Final Publishable Summary

Executive Summary (1p maximum)

European seismic engineering research suffers from extreme fragmentation of Research Infrastructures (RI) between countries and limited access to them by the European scientific and technical (S&T) earthquake engineering community, especially that of Europe's most seismic regions. Through the project SERIES (Seismic Engineering Research Infrastructures for European Synergies) www.series.upatras.gr of the 7th Framework Programme (2007-2013), the European Commission has brought together essentially all European RIs in structural and geotechnical earthquake engineering into a seamless and sustainable platform of co-operation and outreach to the European community of science, technology and practice in earthquake engineering, in order to share with it their experimental capabilities and the fruits of their research. SERIES has also helped the RIs enhance their own potential, by exchanging knowhow, pooling their human resources and jointly developing novel seismic testing systems and techniques.

These goals have been achieved via a portfolio of:

- Networking Activities (NAs), notably a large distributed virtual database of seismic test results (aspiring to become one of the world's top sources of data in experimental earthquake engineering), telepresence in testing at the RIs, development and pilot application of a protocol for qualification of seismic RIs (aspiring to become a draft European standard), training of RI users and own staff, development of the capability of RIs for geographically distributed concurrent testing, collaboration with national and international networks, dissemination through four international workshops, etc.
- Joint Research Activities (JRAs) toward new fundamental technologies and techniques for efficient and joint use of the RIs' resources, in areas where the consortium excels at world level. Namely: development of new-generation dynamic actuators (including different types thereof) for high-performance and capacity and enhanced quality in dynamic testing; new instrumentation and sensors for improved sensing and test control; dedicated software for data collection, processing and communication, serving current needs for model calibration and interpretation of structural response; data assimilation and model updating for virtual models of equipment-specimen systems; use of recent advances in control, to reduce calibration pre-tests, optimise instrumentation and improve the quality of results; and new capabilities and techniques for the experimental study of soil-structure-interaction and seismic wave propagation phenomena.
- Free-of-charge Transnational Access (TA) and support to European researchers to carry out experimental research at EU's four largest shaking tables and largest reaction wall and pseudodynamic testing facility, and two unique centrifuge testing laboratories. After several rounds of open calls for proposals, peer-review and evaluation by an 11-strong panel of experts, 27 TA projects were selected, encompassing 210 researchers from 22 European countries.

The end of the project coincides with the beginning of the multi-year process of the revision of the first European Standard (EN) for earthquake resistant structures, Eurocode 8, toward a second generation EN. Some of the findings of the TA projects and some of the outcomes of the JRAs and NAs (including the large database of past test results) will be exploited for this revision.

Project context and main objectives (4p maximum)

Despite large investments over the past decades, European seismic engineering research suffers from extreme fragmentation of Research Infrastructures (RI) between countries and limited access to them by the scientific earthquake engineering community, especially that of Europe's most seismic regions. There is no hub for seismic engineering research, because individually none of Europe's research infrastructures has the critical mass of people and the broad range of experimental capability or expertise needed for major breakthroughs in the state-of-the-art.
The goal of the European Commission (EC) is to bolster the efficiency of research facilities and the human capital in earthquake engineering, by sharing infrastructures and resources across Europe in the framework of the 53-month project SERIES (Seismic Engineering Research Infrastructures for European Synergies, www.series.upatras.gr), funded by the Seventh Framework Programme of the European Commission for Research (2007-2013).

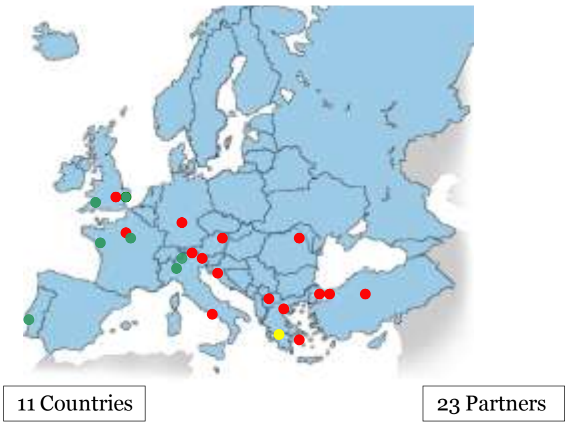
The SERIES project has addressed the fragmentation, inefficiency and sub-optimal use of European research infrastructures by creating a 23-strong partnership of the major European players in earthquake engineering and opening up the top research infrastructures to the wider European earthquake engineering research community. SERIES brings together that community via a portfolio of:

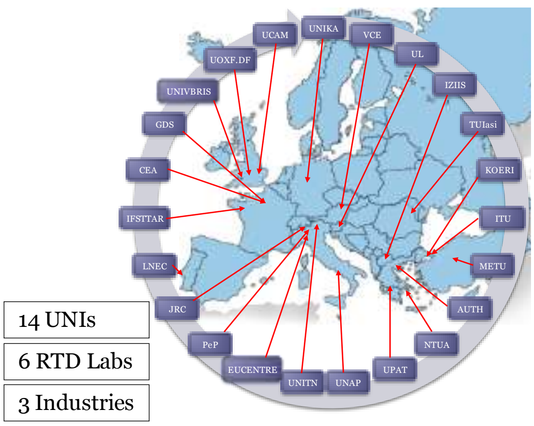
- Networking Activities:
  - a large distributed (virtual) database of test results;
  - telepresence in testing;
  - standards, protocols and criteria for qualification of seismic research infrastructures;
  - training of users of the infrastructures;
  - capability for geographically distributed concurrent testing;
  - collaboration with national and international initiatives;
  - dissemination through four international workshops, etc.
- Free-of-charge Transnational Access (TA) and support to European researchers to carry out experimental research at:
  - EU's four largest shaking tables;
  - EU's largest reaction wall and pseudodynamic (PsD) testing facility and
  - two unique centrifuge testing laboratories.
- Joint Research Activities, toward new fundamental technologies and techniques for efficient and joint use of seismic research infrastructures, in areas where the consortium excels at world level:
  - development of new-generation dynamic actuators (including combination of different types of actuators) for high-performance and capacity, and enhanced quality in dynamic testing;
  - new instrumentation and sensors for improved sensing and test control; dedicated software for data collection, processing and communication, serving current needs for model calibration and interpretation of structural response;
  - data assimilation and model updating for virtual models of equipment-specimen systems;
  - use of recent advances in control, to reduce calibration pre-tests, optimise instrumentation and improve the quality of results;
  - new capabilities and techniques for experimental study of soil-structure-interaction and seismic wave propagation phenomena.

The SERIES Consortium

University of Patras (UPAT) *	GR
Aristotle University of Thessaloniki (AUTH)	GR
Commissariat à l'Énergie Atomique et aux Energies Alternatives (CEA) ‡	FR
Centro Europeo di Formazione e Ricerca in Ingegneria Sismica (EUCENTRE) ‡	IT
Géodynamique et Structure (GDS)	FR
Technical University of Istanbul (ITU)	TR
Institute of Earthquake Engineering and Engineering Seismology (IZIIS)	MK
ELSA, JRC (Ispra) ‡	EC/IT
Bogazici University - Kandili Observatory and Earthquake Research Institute (KOERI)	TR
Institut Francais des Sciences et Technologies des Transports, de l'Amenagement et des Reseaux (IFSTTAR - formerly LCPC) ‡	FR
Laboratório Nacional de Engenharia Civil (LNEC) ‡	PT
Middle East Technical University (METU)	TR
National Technical University of Athens (NTUA)	GR
P&P LMC Srl (PeP)	IT
Technical University 'Gheorghe Asachi' of Iasi (TUIasi)	RO
University of Cambridge (UCAM) ‡	UK
University of Ljubljana (UL)	SI
Universita degli Studi di Napoli Federico II (UNAP)	IT
Universität Kassel (UNIKA)	GE
Universitá degli Studi di Trento (UNITN)	IT
University of Bristol (UNIVBRIS) ‡	UK
University of Oxford (UOXFD.DF) ‡	UK
VCE Holding GmbH (VCE)	AT

– * Co-ordinator
– ‡ Facility offering Transnational Access (TNA) to Users





SERIES beneficiaries across Europe
(green dots: TA facilities; yellow: the co-ordinator; red dots: other partners).

The Consortium of SERIES beneficiaries is listed in the table above. Its geographic distribution across Europe is depicted in the above figures.

The Consortium comprises essentially every experimental research infrastructure in Europe in the fields of structural or geotechnical earthquake engineering. Its 20 laboratories cover in a complementary way the full range of seismic testing techniques and capabilities:

- Pseudo-dynamic testing at eight Reaction Wall facilities, including EU’s largest in ELSA, at the JRC (Ispra, IT);
- Shaking Table testing at ten facilities with diverse capabilities and technical characteristics, some of them of world-class.
- Centrifuge Testing at two world-leader, pioneering geotechnical laboratories;
- a dedicated Testing System for Seismic Bearings and Isolation/Dissipation Devices;
- an Experimental Test Site for site effects and wave propagation.

In addition, the Consortium includes three private industrial partners (two design and consulting firms and a consultancy and laboratory firm), with large experience and expertise in seismic applications.

One of the objectives of SERIES is to pave the way for smaller but up-and-coming research infrastructures to develop further in the framework of a dynamic map of seismic research infrastructures in Europe.

Main S & T Results / Foregrounds (25p maximum)

Networking activities (NA)

The networking activities:

1. reach out to Europe's widest possible community of science, technology and practice in earthquake engineering, to spread the outcomes of the RIs, increase awareness of their capabilities and attract users to benefit from them during and after SERIES; and
2. establish a seamless and sustainable platform of co-operation between the European RIs in earthquake engineering, developing synergies and complementarities between them and fostering their joint development in terms of performance and access.

The outreach to the European scientific, technical and professional earthquake engineering community has been pursued via the European Association of Earthquake Engineering (EAEE), the European body in charge of drafting and maintaining EN Eurocode 8, the International Federation of Structural Concrete (***fib***), the European Earthquake Protection Initiative (EEPI), national networks, such as ReLUIS (IT) and UK-NEES, training courses, four international open Workshops and telepresence to tests carried out at the SERIES RIs.

The four Workshops were organised:

- in Iasi (RO), in July 2009;
- in Ohrid (MK), in September 2010 - in conjunction with the 14th European Conference on Earthquake Engineering;
- in Istanbul, in February 2012;
- in Ispra (IT), in May 2013 - jointly with the US Network for Earthquake Engineering Simulation (US-NEES).

Hardbound volumes of the Proceedings of each Workshop, except the first one, were published after peer review by Springer, as part of its reputed series in Geotechnical, Geological and Earthquake Engineering. Their titles and other details are:

- "Role of Seismic Testing Facilities in Performance-based Earthquake Engineering" Springer, ISBN 978-94-007-1976-7, Oct. 2011 (M.N. Fardis, Z. Rakicevic, eds), 384p.
- "Seismic Evaluation and Rehabilitation of Structures" Springer, ISBN 978-3-319-00457-0, August 2013 (A. Ilki, M.N. Fardis, eds), 455p.
- "Experimental Research in Earthquake Engineering", Springer, September 2014 (expected) (F. Taucer, ed), circa 600p.

There were six training courses on advances in testing and good operation practice in RIs:

- A preparatory course on experimental testing and theoretical background, EUCENTRE, Pavia (IT), March 2010, 31 attendees.
- A course on PsD Testing, JRC, Ispra (IT), Nov. 2010, 21 attendees.
- A course on seismic qualification, UNIVBRIS, Bristol (UK), Jan. 2011, 17 attendees;
- A course on physical modelling in centrifuge tests, IFSTTAR (in collaboration with UCAM), Nantes (FR), March 2011, 16 attendees;
- A course on shake table testing, including data reduction and interpretation, CEA, Saclay (FR), Jan. 2012, 22 attendees;
- Another course on shake table testing, with hands-on practical application, LNEC September 2012, 8 attendees.

The SERIES website: http://www.series.upatras.gr/training_courses gives access to the presentations and the course lecture notes.

Finally, most labs in SERIES have established the capability of telepresence and use it routinely to disseminate their experimental activities live (online) or off-line.

The platform of co-operation between the RIs comprises:

- A corporate web-portal (www.series.upatras.gr) as the central contact point and main reference point for RIs in earthquake engineering in Europe, during the project and afterwards. It provides education and dissemination material, information on TA, workshops and training courses, telepresence in experimental activities, repository of scientific knowledge (including that generated during SERIES), information on the qualification of RI, access to the distributed database (see below), etc.
- A distributed (virtual) database of experimental information, whereby the data stay at the individual facility and a communication protocol ensures their transfer to the end user in a common language and format. It contains experimental data and all supporting documentation: data generated by the RIs during SERIES, past data from the very RIs and from the literature, and new data to be uploaded in the future. It aspires to become the world's largest source of experimental information in earthquake engineering. It provides real-time access to data generated during experimental campaigns and on-line access and interaction through telepresence and distributed testing.
- Capability for geographically distributed, concurrent testing at several research infrastructures, enlarging their individual capabilities and profiting from their complementarities. It encompasses RIs possessing Reaction Walls and PsD testing capabilities, large or small.
- A common protocol for qualification of earthquake engineering RIs in Europe, ensuring reliability of testing via repeatability and reproducibility. After establishing the general reliability of structural testing in Europe, a draft Common Protocol has been produced for the qualification of RIs in earthquake engineering, detailing the technical rules and the quality assurance approach to be adopted as a condition for mutual accreditation of a seismic testing laboratory. Seven SERIES RIs, namely three TA facilities (CEA, EUCENTRE, JRC) and four other labs (IZIIS, NTUA, UNAP, UNITN) implemented the protocol on a voluntary and pilot basis, to identify potential difficulties in application. On the basis of the lessons learned, the draft protocol has been revised into a final Common Protocol for the qualification of RIs in earthquake engineering. The final Protocol includes in Annexes a Check List for the performance of the Audit to the RI and Specific Technical Requirements for Shake Table testing, seismic On-site testing, Reaction Wall testing, and for Data Acquisition and Processing. SERIES has started a campaign around the EU for the establishment of a European Standard for qualification of earthquake engineering RIs, using as the basis the final Common Protocol.

Transnational access (TA)

Free-of-charge TA and support has been provided to European researchers to carry out experimental research at EU's four largest shaking tables, EU's largest reaction wall and pseudodynamic (PsD) testing facility, and two unique centrifuge test labs.
TA opportunities in SERIES were publicized from the outset via:

- direct circular emailing from the co-ordinator to over 500 potential TA Users throughout Europe;
- the websites of the project and of the seven research infrastructures offering TA;
- the international Workshop “Opportunities for users to access European research infrastructures in earthquake engineering”, which was held in Iasi (RO) in July 2009; and
- the European Association of Earthquake Engineering (EAEE).

The calls were open to international teams of researchers established in European countries, who count not as representatives of their Organisation but as individuals. A "Lead User" represents the User team toward SERIES. He/she and the majority of the Users in a team should be working in an institution of an EU Member State or Associated country, but other than the one where the TA facility is established. Five calls for proposals were made during the course of SERIES.

Right after a call's deadline, the full proposals were sent to the members of an 11-strong User Selection Panel (USP), comprising the co-ordinator, one representative from each TA facility and three high-level external experts. Few days after, the USP met to discuss and evaluate each individual proposal. After each discussion, every USP member present at the meeting graded independently the proposal according to a set of 13 weighted criteria. In addition to the proposal's scientific merit and originality, the proposing team's quality, size and internationality, the criteria considered – but in this case negatively – the use of the TA facility by anyone in the User group in the past (even before SERIES) and the availability of similar research infrastructures in any of the Users' countries. Should the USP-average in a single criterion fall below 6 out of 10, the proposal was rejected. Non-rejected proposals were accepted, unless the TA facility exceeded the limit of "access days" it could provide to TA Users according to the EC Grant Agreement. An "access day" is one when the main pieces of equipment to be used for testing – the shaking table, the bucket of the centrifuge, the PsD actuators and control system, etc. – are meant to be exclusively occupied by the specific TA project, normally with the structural control hooked up to the loading system and the data acquisition systems to the instrumentation.

The "Lead User" of a successful proposal was then called to sign with the TNA facility a TNA Contract Agreement, delineating the tasks and responsibilities of the two sides and the technical details of the project to be carried out. It is via this Agreement that the general terms of the SERIES EC Grant Agreement were extended from the TNA facility to the team of TNA Users.

Free-of-charge services offered to the TA Users include:

- technical assistance to define and design the test model and set-up and the input signals;
- fabrication of test models and preliminary tests for material properties, as relevant;
- technical assistance to design, calibrate and implement the instrumentation;
- data acquisition systems, visual records of the model before, during and after testing;
- use of analytical tools for the design of the model and the test campaign and for pre-test analysis;
- data processing, analysis and repository system accessed via Internet, interpretation of test results;
- training specific to the Users' interest and the TA project;
- a test report co-authored by the Users;
- travel and subsistence for short stays.

Transnational Access (TA) projects

Project	Lead User	TA facility	Testing
Seismic retrofitting of RC frames with RC infilling	C. Chrysostomou, Cyprus Un. of Technology (CY)	ELSA/JRC	Reaction wall –PsD
Seismic vulnerability of old RC viaduct with frame piers. Effectiveness of isolation system	F. Paolacci, Un. di Roma Tre (IT)	ELSA/JRC	Reaction wall –PsD
Full-scale experimental validation of dual eccentrically braced frame with removable links	D. Dubina, Technical Un. Timisoara (RO)	ELSA/JRC	Reaction wall –PsD
Polyfunctional technical textiles for protection & monitoring of masonry structures in earthquakes	L. Stempniewski, Karlsruhe Inst. of Technology (DE)	EUCENTRE	Shake table
Seismic behaviour of structural systems composed of cast-in-situ concrete walls	S. Ivorra, Un. of Alicante (ES)	EUCENTRE	Shake table
Seismic behaviour of mixed reinforced concrete-unreinforced masonry wall structures	K. Beyer, EPFL (CH)	EUCENTRE	Shake table
Experimental and numerical study of shear wall RC buildings under torsional effects	A. Yakut, METU (TR)	CEA	Shake table
Seismic strengthening of deficient RC buildings with ductile post-tensioned metal strips	K. Pilakoutas, Un. of Sheffield (UK)	CEA	Shake table
Improved European design and assessment methods for concentrically-braced frames	B. Broderick, Trinity College Dublin (IR)	CEA	Shake table
Seismic performance of multi-storey timber buildings	M. Piazza, R. Tomasi, Un. di Trento (IT)	LNEC	Shake table
Tests of historic architecture retrofitted with energy dissipators	D. D’Ayala, Bath University (UK)	LNEC	Shake table
Full scale testing of modern unreinforced thermal insulation clay block masonry houses	S. Lu, Wienerberger AG (AT)	LNEC	Shake table
Assessment of innovative solutions for non-load bearing masonry enclosures	E. Vintzileou, NTUA (GR)	LNEC	Shake table
High-performance composite-reinforced earthquake resistant buildings with self-aligning capabilities	B. Kasal, Fraunhofer WKI (DE) & ITAM (CZ)	Bristol University	Shake table
Seismic behavior of L- and T-shaped unreinforced masonry walls with acoustic insulation devices	H. Degee, Un. de Liège (BE)	Bristol University	Shake table
Assessment of the seismic behaviour of flat-bottom silos containing grain-like materials	D. Foti, Un. di Bari (IT)	Bristol University	Shake table
Study of multi-building interactions and site-city effect via idealized experimental model	P.Y. Bard, Un. J. Fourier, Grenoble (FR)	Bristol University	Shake table
Experimental investigation of dynamic behaviour of cantilever retaining walls	A. Evangelista, Un. di Napoli (IT)	Bristol University	Shear stack, Shake table
Dynamic behaviour of soils reinforced with long inclusions (piles)	C. Boutin, ENTPE (FR)	Bristol University	Shear stack, Shake table
Soil-Pile-Structure Seismic Interaction	A.L. Simonelli, Un. di Sannio (IT)	Bristol University	Shear stack, Shake table
Centrifuge modeling of dynamic behaviour of box shaped underground structures in sand	Y. Özkan, METU (TR)	IFSTTAR (ex LCPC)	Centrifuge
Studies of nonlinearity in soils using advanced laboratory-scaled models	G. Scarascia, Un. di Roma la Sapienza (IT)	IFSTTAR (ex LCPC)	Centrifuge
Seismic behavior of shallow rectangular underground structures in soft soil	E. Rovithis, ITSAK (GR)	IFSTTAR (ex LCPC)	Centrifuge
Experimental verification of shallow foundation performance in earthquake-induced liquefaction	G. Bouckovalas, NTUA (GR)	Cambridge University	Centrifuge
Shallow foundations in seismic liquefaction: Study of level, mitigation of effects	P.A. Coelho, Coimbra University (PT)	Cambridge University	Centrifuge
Seismic performance of propped flexible retaining walls embedded in saturated sand	G. Viggiani, Un. di Roma Tor Vergata (IT)	Cambridge University	Centrifuge
Investigation of seismic behaviour of shallow rectangular underground structures in soft soils	K. Pitilakis, Un. of Thessaloniki (GR)	Cambridge University	Centrifuge

Countries where User organisations participating in at least one TA project and Lead Users were established

	AT	BE	CH	CY	CZ	DE	ES	FR	GR	IE	IS	IT	MK	NL	NO	PL	PT	RO	SK	SI	TR	UK
User organisations	4	2	4	2	2	8	4	6	8	2	1	20	1	1	2	2	4	3	1	2	3	5
Lead User	1	1	1	1	-	2	1	2	4	1	-	7	-	-	-	-	1	1	-	-	2	2

48 proposals were submitted in five rounds of open calls. They were reviewed and evaluated as described above. 27 proposals were accepted and assigned to the seven TA facilities as shown in the two Tables above.

After conclusion of a TA project, the Lead User fills online at the European Commission's webportal a TA User questionnaire, accessible only to the European Commission. After completion of a TA project in every respect (including treatment and compilation of the data, analysis, comparison of test results to numerical or analytical outcomes, etc), the User team produces a final report, available to the public through the SERIES website. Lead Users have also been invited to fill another TA User questionnaire, accessible only to the very TA facility, whose aim is to help the facility evaluate its own performance and improve in the future the services it provides.

The SERIES "Concluding Workshop" in May 2013 reached the following ***"conclusions concerning the TA projects in SERIES":***

- *The TA projects not only gave the opportunity to researchers from the outside to use the advanced experimental facilities and knowhow in Europe's best seismic RIs, but also allowed the flow of fresh ideas to the facilities and the interaction with high-level researchers, to the benefit of both sides.*
- *The involvement of industry in TA projects is remarkable, with potential benefits to innovation in seismic design practice in Europe.*

As it is mainly through the TA projects that SERIES produced new S & T knowledge, the 27 projects and their foregrounds are presented individually at the end of this part of the Publishable Summary.

Joint Research Activity JRA1: Novel Actuation Systems for Real-Time Control

JRA1 concerns the appraisal of alternatives to servo-hydraulic actuation for seismic testing, to improve fidelity and extend the scope. The performance requirements of common earthquake engineering actuation devices have been surveyed and the need for high-force electrical actuators that provide both capacity and precision has been identified. Future high-performance actuation systems may see electrical actuators as direct replacements for servo-hydraulic ones or as subcomponents in hybrid actuation systems that employ both types of actuators. Alternative actuator technologies that satisfy the performance requirements and improve the range of operation frequencies have been identified, classified and evaluated technically, alongside the problems associated with combining different technologies.

As an alternative to servo-hydraulic systems, two types of electrical actuators have been investigated experimentally. The first one is electro-mechanical, consisting of a screw mechanism driven by an electric motor through a reduction gearbox. The second type is electro-magnetic, with the actuator piston driven directly by control of high-capacity rare-earth electro-magnets. In both cases, the load capacity of commercially available systems is limited to around 10 kN, at the bottom end of the useful range for structural testing. They are both usable with careful filtering to deal with electrical noise in instrumentation, with the electro-mechanical ones being more versatile, compact and easy to control.

Concrete final results are:

1. A novel dual servo-valve manifold, alongside the associated control architecture, providing high fidelity, wide bandwidth control of the powerful servo-hydraulic actuation systems necessary for seismic testing with large loads and high velocity.
2. Development and prototyping of a novel tandem actuation system, patented under the title: "Hydraulic drive for fatigue tests, use of a multiple cylinder for fatigue tests and method of controlling the hydraulic drive". The new actuator drastically reduces the energy demand in fatigue testing. It consists of two cylinders of different size, with plain bearing devices compensating the adverse effects of lateral loading. The piston rod of the first cylinder pushes through the bottom of the other to its piston area: the first stage, controlled in force, produces large forces; the second one, generally smaller and controlled in displacement, provides high displacement accuracy.
3. Redesign of ELSA's legacy control architecture for multi-actuator pseudo-dynamic tests, removing the limitation on the number of actuation devices that can be implemented in a test and improving the imposed boundary conditions.
4. A method for accurate, stable and reliable actuator control for geographically distributed testing, accommodating network jitter and negating actuator delay via adaptive phase lag compensation.

Other proposed improvements to servo-hydraulic test systems include:

- Reichert's directly controlled piezo-servovalve with many desirable features, but needing further testing to assess its suitability for seismic structural testing.
- A novel design hybrid actuator with piezo-actuators inside the cylinder of a servo-hydraulic one to impose small, high-frequency changes on the oil volume to improve high frequency response.

Joint Research Activity JRA2: Advanced Sensing, Data Processing and Modelling

The objectives of JRA2 are:

1. Implementation and application of new types of sensors for improved sensing and control: new types of instrumentation (wireless, fibre optics, 3D visualization tools) and techniques for measuring structural and foundation response, explored and calibrated/validated in tests.
2. Numerical tools for processing data from experiments on structures and foundations, suitable for model calibration or specimen simulation and assessment of the uncertain propagation of random or systematic errors in computer models owing to experimental measurements.
3. Use of recent advances in model updating to develop complete virtual models of the test equipment-specimen-instrumentation system for optimised calibration pre-tests and improvement of the quality of results.

To serve the first one of these objectives, in-depth analysis has been carried out using integration methods, adaptive control strategies for real-time substructuring tests, optimized PID control, internal model control, model predictive control, combined inverse-dynamics, adaptive control for instrumentation control, optical sensors for displacement measurement, wireless sensors for strain or acceleration measurements and error assessment. Control techniques were tested in real-time tests on a testing bench comprising four electro-magnetic actuators controlling four-

Degree-of-Freedom linear/non-linear systems with or without substructuring (both with monolithic and partitioned time integration algorithms and optimized PID and Internal Model Controllers), as well as on a base-isolated structure with spherical sliding bearing, and a shaking table test with substructuring. The performance of optical fibres based on the FBG technique was assessed on concrete tunnel linings substructures; those of wireless MEMS for measuring strains and accelerations on one-storey, one-bay concrete structure. Measurement systems using lasers, gyroscopic sensors and vision systems were designed and used to capture displacement fields on specimens shaken on shaking tables. Vision systems, either texture- or target-tracking were employed with cameras to measure displacements, rotations and deformations in a PsD test of a bridge model.

Software developed for data processing (second objective above) includes:

- a portable data processing tool in the LabView platform for dynamic tests;
- software for modal parameter extraction and identification of modal properties and damping from dynamic response of components and systems;
- a Performance-based Earthquake Engineering toolbox in Matlab, in combination with a Finite Element (FE) code, for post-processing of results of pseudo-dynamic tests and identification of errors in structural models;
- software for structural health monitoring of structures in situ, in order to track changes in dynamic characteristics and detect damage with simple web-based real-time data analysis;
- Software for parametric or non-parametric identification of hysteretic systems;
- Software for 3D animation of modal shapes from FE outputs;
- MATLAB software for 3D animation of real-time tests.

Integration of modelling with test equipment for virtual models (third objective above) includes development and application in real time and/or pseudo-dynamic testing of:

- experimental transfer functions to identify the dynamics of shake table systems;
- an offline tuning method of shaking tables via simplified FE models of specimens;
- a nonlinear identification technique of hysteretic restoring forces for statically indeterminate systems under seismic excitations;
- implementation of the interfield Pegon-Magonette method using the OpenSees FE and the OpenFresco software.

Joint Research Activity JRA3: Testing techniques for Soil Structure Interaction (SSI) and wave propagation

JRA3 develops new capabilities and techniques for experimental studies of wave propagation and SSI phenomena for surface and embedded structures, beyond what is current practice of experimental research. Strong ground motion estimates as appropriate input motion for SSI studies are also included. More specifically, the following were carried out and achieved:

1. Field techniques, including permanent and temporary arrays to study wave propagation in complex media, especially the waves generated by the structure vibration (surface or embedded) and the spatial variability of the ground motion: field testing techniques have been developed for the shear wave velocity and shear modulus in soil formations, with emphasis on geophysical techniques and inverse analysis, including methods for estimation of wave fields propagating underneath and around oscillating structures. The techniques have been applied in

numerous case studies around Europe and have been numerically calibrated using data from centrifuge or shake table testing and models. Contributions were made toward a new set of amplification factors for soil classes in Eurocode 8, alongside a new soil classification system and normalized acceleration spectra.

2. Calibration of SSI test techniques through centrifuge testing: calibration tests were carried out on single-degree-of-freedom lumped mass structures or sway-frames on dry sand of different relative densities at the two centrifuge centres, focusing on repeatability. The quality of input acceleration signals in centrifuge tests, the response of the foundation soil and the super-structure and the instrumentation used, were assessed. Better insights into the effect of structural surcharge and soil density were gained. Centrifuge testing has been found to be directly comparable to shake table tests, simplified numerical analyses and in-situ field experiments performed in other tasks of JRA3, offering a sound basis for calibration/validation of numerical models and comparison with other types of testing.
3. Calibration of SSI test techniques by means of Pseudo-dynamic (PsD) tests: the behaviour of shallow foundations under cyclic loading in past PsD tests has been studied, with emphasis on the identification of the non-linear mechanisms leading to the development of permanent settlements and tilt of the foundation. A nonlinear macroelement has been developed for SSI in shallow foundations, capable of reproducing the observed foundation settlements and tilts in cohesive or frictional soils and of accounting for dynamic phenomena, like radiation damping, frequency-dependence of foundation impedance, effect of soil inertia forces, etc. It has been validated on the basis of SSI tests in a centrifuge, on a shake table or in the field, extensively used in applications and utilised to develop guidelines for foundation system identification and a test protocol in PsD testing including SSI.
4. Calibration of SSI test techniques via shake table testing: the impact of the stiffness and inertia of the laminates and of boundary reflections in 1g laminar boxes has been studied and a simplified methodology for their numerical simulation developed. Two independent innovative designs for soil containers (shear stacks) in strong motion testing were proposed, to minimise boundary reflections, enhance performance and introduce novel actuation technologies. Fast Hybrid Testing (FHT), modeling the soil numerically and the superstructure physically on the shake table, was implemented with novelties to a SSI problem in two shake table labs. The challenges in FHT with the soil modeled physically on the shake table and the superstructure numerically were identified and ways to face them were studied.
5. Calibration of SSI test techniques via fault-rupture box testing: Fault rupture propagation and its interaction with shallow or deep rigid foundation systems were studied, leading to identification of foundation failure mechanisms due to fault rupture. From the experimental and numerical results obtained, a simplified method was developed for estimation of faulting-induced stresses on structures.
6. Calibration of field testing techniques to assess SSI: SSI effects on the structural response of model structures have been studied in real-scale under shock excitation, using monitoring systems developed in JRA2 and numerical simulations. Real-scale field test results were compared with reduced-scale ones from centrifuge and shake table tests, for cross-assessment of these techniques.

TA Projects: S & T Results and Foregrounds

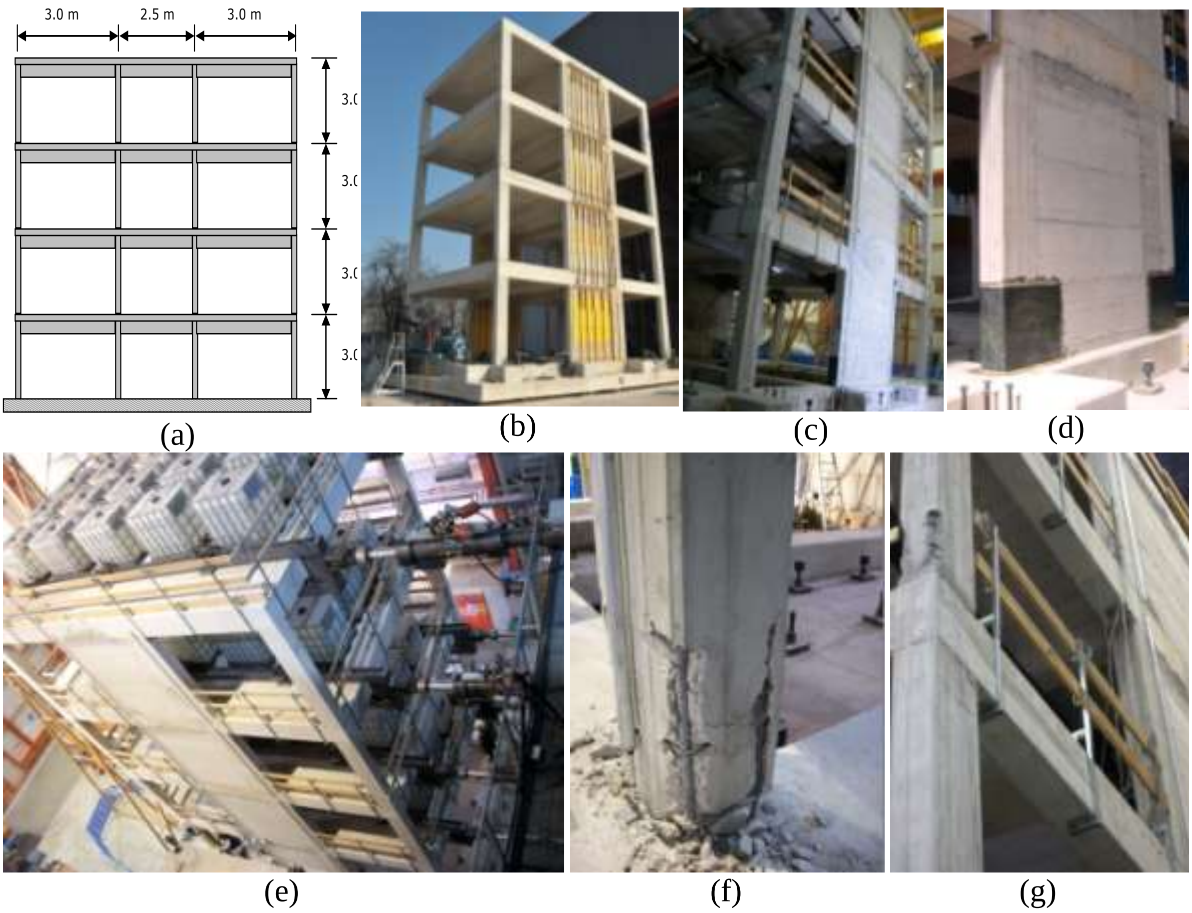


Figure 1: (a) overall RC frame dimensions; (b) RC-infilling of central bay; (c) completed structure; (d) FRP-jacketing of column-edges at the base of composite wall (e) PsD testing at ELSA Reaction Wall; (f) damaged base of ground floor column; (g) damage at the base of a 3rd storey column.

Seismic retrofitting of RC frames with RC infilling

Added reinforced concrete (RC) walls are very popular in seismic retrofitting of RC buildings. A simple and cost-effective way of adding walls is to infill with RC selected bays of the existing frame, especially on the perimeter. If the new wall takes up a full bay, it can incorporate the beams and both columns, at the location normally taken up by the wall boundary elements. The web is fully new and should be fastened to the old beams and columns so as to transfer to them the full web shear and the tensile capacity of the two-way web reinforcement. Poor detailing of the connection between the old and the new may lead to premature failure and low ductility. Besides, if the connection between the old and the new is not integral, the behaviour is uncertain; modelling and verification of the wall as a single, integral element is then questionable. For integral behaviour, the wall is often built thick enough to encapsulate the old beams and columns, correcting column deficiencies due to short lap splices of vertical bars and sparse ties. The resulting composite wall may be modelled and verified as a monolithic new member; however, it may be much stronger than necessary for upgrading the building as a whole, or create difficulties for the foundation. To reduce this overstrength and avoid piercing through the slabs for continuity of vertical bars across floors, the new web may be chosen not thicker than the beams and columns of the frame. In that case the shear connection of the web to the surrounding frame members may be the critical link. Even for a very good connection, integral behaviour of the old and the new cannot be taken for granted; there is still uncertainty about the magnitude of the force- and moment-resistance of the composite system and its deformation capacity. Two alternative connections of the old frame members to a thin added web were tried in this project: one with tensile anchorage of the two-way web reinforcement into the surrounding frame and separate dowels for shear transfer at the interface, or a more economic option, with longer dowels serving both goals. The test structure included in full scale the two 8.9 m long outer frames of a 4-storey, 4-frame RC building, with the 2.5m wide central bay infilled into a RC wall of the same thickness as the columns (Fig. 1). The reinforcement of the added web was different in the two frames of the test structure, it was also different from storey to storey and used the two different connection types at opposite sides or at the top and bottom of selected web panels. U-shaped FRP jackets were added around each edge of the composite wall at the base (Fig. 1(d)). In the PsD test, a historic record, modified to fit the 5%-damped Eurocode 8 Type 1 spectrum over soil C at a PGA of 0.25g, was applied parallel to the RC-infilled frames (Fig. 1(e)). The composite wall behaved as essentially monolithic and had no diagonal cracking. Flexural deformations were concentrated in a horizontal crack at the connection of the wall to the base. Slippage along that crack did not exceed 0.8 mm or 0.4 mm along the vertical interfaces of the web and the old columns. The two types of connection had essentially the same effectiveness and the U-shaped FRP jackets fully protected the poorly detailed bottom of the frame columns at the edge of the walls. By contrast, the similar, but unprotected, corner columns failed in flexure at the laps at ground level (Fig. 1(f)), as well as at the base of the 3rd storey (Fig. 1(g)). The beams yielded at both ends in almost every storey. There was no noticeable drop in the overall lateral force resistance during the 0.25g PGA test, even at roof drifts of over 0.9%. By contrast, the weaker of the two sides of the buidling conventionally failed (i.e., had a 20% drop in lateral force resistance) at a roof drift of 1.05% in a cyclic test under inverted triangular lateral loads.

Seismic vulnerability of old RC viaduct with frame piers. Effectiveness of isolation system

The seismic vulnerability of existing and new transportation systems is of paramount importance for modern societies. Transportation systems were built worldwide mainly in the 1960s or 1970s; so, most of their bridges are not designed for seismic loadings. This project studied the seismic behaviour of existing reinforced concrete (RC) bridges, designed for gravity loads and the effectiveness of innovative retrofitting systems. An existing Italian viaduct with portal frame piers (Rio Torto Viaduct) was evaluated and an isolation system was designed based on frictional devices with spherical sliding surface. Two twin 1:2.5 scale, RC piers one with two transverse girders and total height of 6.8 m and another with three and a total height of 11.2 m, were PsD tested with sub-structuring, with a total of 18 controlled Degrees-of-Freedom (DOFs) (Fig. 2). The entire viaduct was modelled, considering the nonlinear response of each pier, due to bending, shear in the transverse beams and slippage of pier column bars from the foundation. Both the “as-built” viaduct and the one retrofitted with seismic isolation were tested. The isolation system was tested separately from the two piers, with substructuring. Two different natural records were applied, from the 2011 Emilia earthquake. The test campaign confirmed the high vulnerability of the as-built bridge, suffering extensive damage under the design

earthquake and exacerbated at twice that level, especially in the short pier, where the transverse beam was severely cracked. Large fix-end-rotation at the base of the columns of both piers occurred due to slippage of pier bars from the foundation.
The isolation system proved very effective in reducing the seismic response of the bridge; the isolated bridge responded in a quasi linear-elastic mode at the design earthquake; its base shear was reduced by half and displacements were reduced by 20-30% compared to the non-isolated bridge. The PsD test campaign allows to calibrate numerical models for the assessment of the seismic response of old RC bridges.

(a) (b) (c)

Figure 2 (a) test set-up and geometry; (b) transportation of the tall pier inside the lab; (c) piers in front of the reaction wall.

Full-scale experimental validation of dual eccentrically braced frame with removable seismic links

Most steel structures designed to modern codes would develop inelastic deformations and permanent displacements after major earthquakes. To reduce repair costs and downtime after an earthquake, an innovative steel frame design is proposed, with re-centring capability thanks to removable dissipative seismic links and a dual (rigid-flexible) structural configuration. In a series of PsD tests with seismic link replacement, key points of the concept are assessed: (i) The global seismic performance of a structure with removable links, including the feasibility of replacing the damaged links; (ii) the recentring capability of dual structures with removable seismic links; (iii) the interaction between the concrete slab and the steel structure in the link region. The removable seismic links were designed to provide energy dissipation capacity, while the flexible moment resisting frames remain elastic and provide recentring capability. High strength steel is used in columns to keep them in the elastic range even under strong seismic loading. The full scale, 3-storey test structure is 18 m long, 6 m wide and 10.5 m tall, with two eccentrically braced frames frames in the direction of testing and one removable seismic link per storey and frame. Replacement of the damaged seismic link is performed storey by storey, starting at the top. Once all links are removed, the brace forces are released and the structure recovers its initial position. The snap-back tests on the structure without seismic links have given the first three modal frequencies of 2.5, 5 and 7 Hz and damping ratio of about 5%.

Polyfunctional technical textiles for the protection and monitoring of masonry structures against earthquakes

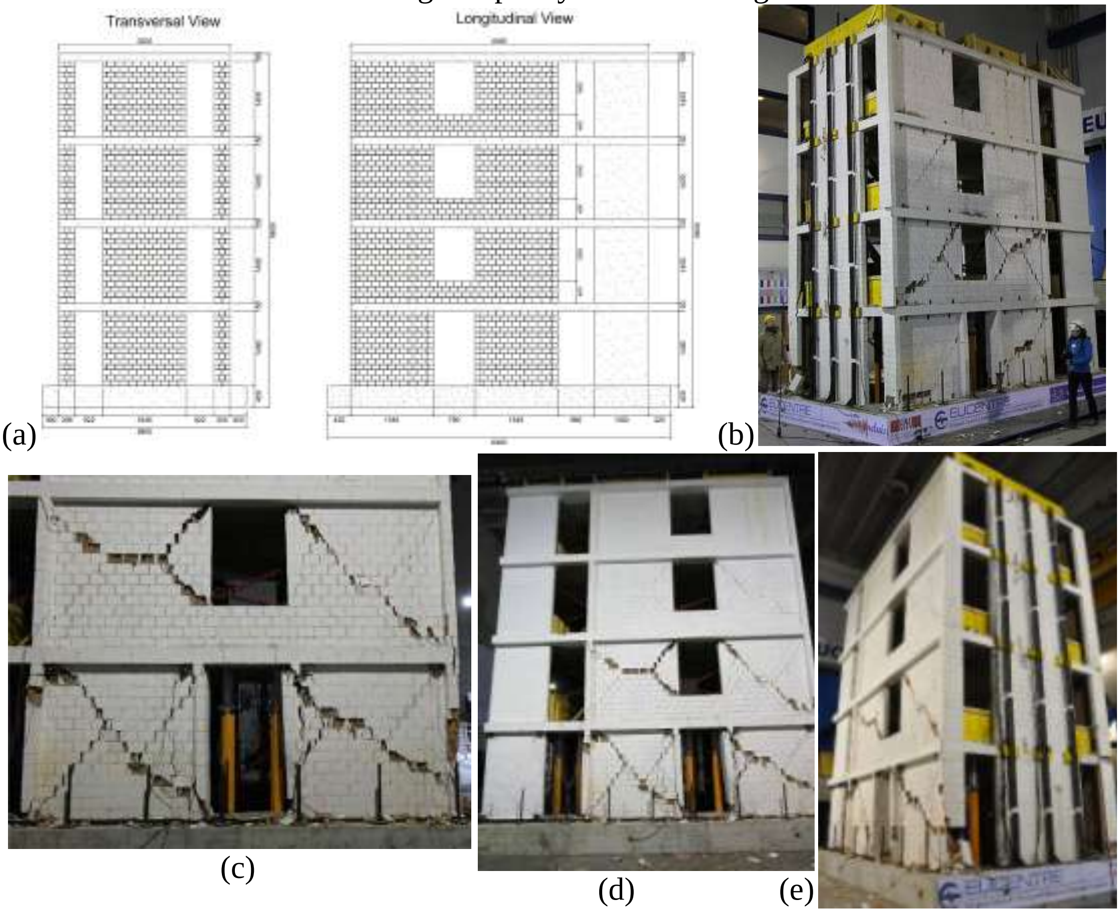
Motivated by buildings damaged in the 2009 L'Aquila earthquake, a two-storey masonry building, 5.8 m tall, 5.8 m long and 4.4 m wide, was subjected to unidirectional shake table testing at five PGA levels, from 0.05g to 0.4g. After the last earthquake level, the unretrofitted building was almost destroyed, with several big cracks (Fig. 3(a)); the very soft wooden floor allowed out-of-plane bending failures of the walls; diagonal bending/tension cracks through the mortar joints over the window were the most important failures and the corner of the building was near collapse. Joint sliding in the "in-plane" walls occurred at the intersection of windows and doors and at the bottom of the wall between doors. Torsional response led to local accelerations of almost 0.9g. High local deformations caused cracks in various directions at the corners. After repair of the displaced roof and the wooden slab, the Eq-grid system was used to repair all the cracks in the masonry (Fig. 3(b),(c)). Eq-grid is applied directly on the stone surface in a special mortar-textile-mortar sandwich configuration. The mortar consists of cement, epoxy resin and hardener. A 425 g/m² heavy glass fibre / polypropylene fabric was developed for repair; it was woven in four fibre directions at angles of 0°, 90° and +/- 30° with the two different fibre materials. The repaired building had no cracks after the test at 0.4g PGA. Further tests at a 0.5g PGA led to microcracks near the windows. At a 0.6g PGA, cracks in the glass fibres occurred under both windows of the out-of-plane side. Delamination between the first layer of mortar and the textile was observed, but the building remained in good shape.

(a) (b) (c)

Figure 3 (a) Cracks of unreinforced masonry building; (b),(c) Reinforced building.

Seismic behaviour of structural systems composed of cast in situ concrete walls

A 3-storey scaled test building has squat cast-in-situ sandwich concrete walls, with 5.50 m length, 4.10 m width and 8.25 m height. Shaking table tests were performed to validate the seismic behaviour of cellular structures composed of squat cast-in-situ sandwich concrete walls. The specimen was built outside the laboratory, lifted and pulled inside using hydraulic jacks and a slider system. A series of shake table tests were performed, with a PGA from 0.05g to 1.2 g and this last test repeated twice. At the end of the experimental campaign the building was essentially undamaged. From the dynamic identification after each test, a slight period shift was found, suggesting some degradation. The structure behaved between uncracked and cracked: up to PGA as high as 1g, there were no major cracks. After a white noise with 0.5g PGA, hairline diffuse cracking appeared, especially at the top floor walls. From the 0.5g white noise to the final 1.2g seismic test, the cracking pattern remained stable. The cellular behaviour of the structure was verified. Important differences between the results of the cyclic tests and the dynamic shake table ones were observed, with respect to the stiffness and the maximum strength capacity of the building.



(a) (b) (c) (d) (e)

Figure 4: (a) Geometry of the model; (b)-(e) structural damage after shake table test

Seismic behaviour of mixed reinforced concrete - unreinforced masonry wall structures

In many residential buildings in Europe, the vertical elements supporting the RC slabs are walls of RC and unreinforced masonry (URM). Although this type of construction is very common in low and moderate seismicity regions, its seismic behaviour has never been studied experimentally in the past. Seismic design codes, notably Eurocode 8, consider the knowledge of the seismic behaviour of such mixed RC-URM systems as still insufficient and do not cover them explicitly. So, nowadays, they can only be considered as concrete structures, with a RC wall structural system. The URM walls are taken as non-structural elements and their contribution to the lateral stiffness and resistance of the building is neglected. The response of this type of buildings was studied by shake table testing. The test structure was a 1:2 scale 4-storey building, 5.6 m × 3.2 m in plan and 6.2 m tall. It has a rectangular RC wall and two I-shaped URM walls of hollow clay blocks, on each one of the two long sides and a rectangular URM wall on each short side (Fig. 4). A unidirectional ground motion was applied in the long direction, inducing in-plane loading in the four URM and the two RC walls along the motion and out-of-plane loading in the two URM walls transverse to it. Nine shake table tests were carried out, with the motion scaled up to a PGA level of 0.9g. Fine cracking appeared in both types of walls of the long direction under a 0.3g PGA motion and became more marked at a PGA of 0.4g. The in-plane damage to the URM walls extended to all storeys under the 0.6g PGA motion, becoming serious at the ground floor. At a PGA level of 0.7g, the damage to the URM walls of the two lower storeys was concentrated in 0.8 mm-wide diagonal cracks. At the 0.9g PGA motion these walls shattered at these two storeys; most of their vertical load was transferred to the two transverse URM walls and the two RC walls. These latter walls cracked diagonally and, when the overturning moment induced tensile force in them, formed a flexural plastic hinge at the base; there was clear axial load variation in these walls due to the overturning moment, which points to the significant participation of the URM walls to the response as part of the lateral load resisting system. The 0.9g-PGA motion caused visible horizontal cracking at the top, bottom and mid-height of one of the two URM walls loaded in the out-of-plane direction; the one further away in plan from the two RC walls, at the storey where floor response accelerations were the largest (the fourth). Measured peak floor accelerations were higher than predicted by the Eurocode 8 approach. If the building had behaved as considered in Eurocode 8, namely as a system of just two cantilever walls, the interstorey drift and the damage to the URM walls would had been largest at the top storey; a pure URM building without RC walls would, by contrast, experience the largest interstorey drifts and damage at the ground floor. The pattern in the test, with similar in-plane damage at the two lowest storeys, shows that the building behaves as a mixed structural system.

Experimental and numerical investigation of torsionally irregular RC shear wall buildings with thermal breakers

The shear wall building was designed in accordance with Eurocode 8. Rutherma thermal breakers were placed only at the second floor as a connection between the shear walls and the slab. Five shake table tests were carried out under a synthetic ground motion matching the Eurocode 8 spectrum. PGA levels of 0.1g, 0.2 g, 0.4g, 0.6g and 0.8g were applied consecutively. Up to 0.4 g, no significant damage was observed in the structural members except minor hairline cracks on the spandrel beams. At the 0.6g test, more cracks were observed in beams without major cracks in the walls. Strain measurements in Rutherma steel sections showed that they were still in the elastic range. Failure occurred in the 0.8g test. The foundation was fully disconnected from the shear wall. The thermal break elements did not have any damage. The open-source finite element code Cast3M-CEA has been used to simulate the tests.

Seismic strengthening of deficient RC buildings with ductile post-tensioned metal strips (PTMS) and Carbon Fibre Reinforced Polymer (CFRP).

A full-scale two-storey RC building is tested, with poor detailing of reinforcement in beam-column joints and columns. Shaking table tests were performed in both horizontal directions X and Y with a single ground motion matching the Eurocode 8 spectrum for soil type C. Increasing levels of PGA from 0.025g to 0.15g were applied to the unretrofitted buildingt in the X direction. At a PGA of 0.15g, there was severe damage at the 2nd floor joints and column bases, where the vertical bars were lapped. The 1st modal frequency was reduced by 45%. The damaged building was repaired (cracks injected, concrete replaced, etc) and strengthened using PTMS. After a PGA of 0.35g, only limited local damage was evident, but the 1st mode frequency dropped by almost 40%. The building was retested with the motion applied in the Y direction, to a PGA of 0.35g. The steel straps were removed then for inspection. Light diagonal cracks at the beam-column joints were observed, but the joints remained structurally sound. Also, flexural cracking occurred at column and beam ends. The damaged concrete was repaired using high-strength repair mortar, and the cracks injected with epoxy resin. The columns and beam-column joints of one of the two frames (frame A) were strengthened with externally bonded CFRP sheets; the other one (frame B) was strengthened again with PTMS. Motions were applied in direction Y up to a PGA of 0.35g, because the 1st modal frequency was almost half of the original one, although little damage was observed. The PTMS and CFRP-strengthened building was then tested triaxially in X, Y and Z, up to a horizontal PGA of 0.60g, because the maximum displacement capacity of the shake table was exhausted (±125 mm in X and Y). Some damage was observed in the joints and columns, but the CFRP sheets and PTMS were essentially undamaged. PTMS and CFRP were found very effective.

Improved European design and assessment methods for concentrically-braced frames

Full scale shake table tests were performed on two-storey concentrically-braced steel frames, to validate models for the ductility capacity of hollow section bracing members and recent proposals for improved detailing of gusset plate connections. The experimental and numerical studies identified active yield mechanisms and failure modes in member/connection combinations and assessed new proposals for the balanced design of brace member-gusset plate connection resistance. Each pair of brace-gusset plate specimens was tested using scaled site-specific ground motions representing high, intermediate and low level earthquakes. Brace buckling and fracture generally occurred at the target intermediate and high level events, respectively. Amongst the four brace sizes investigated, the smaller cross sections exhibited increasing frame drift demands for higher PGA values. The measured brace displacement ductility ratio capacities varied between 2.9 and 12, with a mean of 7.5. Larger ductility capacities were displayed by specimens with smaller cross sections. The proposed balanced brace connection design led to larger brace ductility capacity than the conventional design. The test results suggest that CA type brace connections to the beam and column lead to larger ductility capacity than CB type connections to the beam alone, but the measured data is not fully consistent in this regard.

Seismic performance of multi-storey timber buildings

The goal was to study by shaking table tests on full-scale models the effects of earthquakes on different timber building systems frequently used in Europe: timber framed system (TFS), log house system (LHS) and cross laminated timber system (CLT). Tested were: a) a two-storey log house building, b) a 3-storey timber framed building with oriented strand boards (OSB) as structural sheathing and non-structural panels on the interior and exterior of each wall and c) a light timber-framed wall system with gypsum fibre panels as structural sheathing - Cross Laminated Timber (CLT) system, based on large panels. The tested buildings were 7 m x 5 m in plan, with the same architectural layout, designed to a 0.28g PGA. The test procedure and the prediction of test results was based on advanced calculation models gathered from data acquired in previous experimental campaigns on the individual components (timber elements, connection details, walls and floors with openings, effect of non-structural components etc.). A historic bidirectional motion was applied, scaled to a PGA of 0.07g, 0.15g, 0.28g and 0.5g for all tested specimens. Relative displacements of walls (sliding, uplift), interstorey drift and acceleration were monitored. All constructive systems have shown no significant damage at all stages of the tests. The results provide a wealth of information on the dynamic behaviour of timber buildings and their earthquake resistance.

Tests of historic architecture retrofitted with energy dissipators

This project focused on the seismic retrofitting of masonry buildings, damaged by previous earthquakes, using energy dissipating devices placed on steel ties connecting perpendicular walls. The retrofitting technique is effective when the buildings are damaged at the corners, with vertical cracks opening on the upper part of the walls, while, at the same time, the top part of the wall collapses out of plane to the outside as a single large block after a large horizontal crack opens. The seismic action was imposed in only one direction, the most favorable to overthrow the side walls due to inertia forces, effect further amplified by the horizontal thrust from the roof. However, the flexibility of the façade walls, controlling the global building response in the out-of-plane direction of the side walls, proved more important than expected. Moreover, the distribution of vertical loads along the walls, compressing the side walls at the floor and roof levels but not the façade walls, further weakened these walls, which were already weaker due to the presence of openings. A second set of tests was carried out after redesign of the test setup, to force the formation of the desired collapse mechanism. Modifications included the application of 12 vertical prestressing bars that compressed the façade walls and removal of the two middle supports of the roof structure on the walls, in order to concentrate the horizontal thrusting forces near the corners of the building. The signals were imposed with increasing amplitudes until the collapse mechanism sought was observed.

Full scale testing of modern unreinforced thermal insulation clay block masonry houses

Unreinforced high thermal insulating clay block masonry houses are very common in Europe, but still lacks seismic vulnerability assessment. Two full-scale 2-storey models with dimensions of 3.7m x 4.2 m and a height of 5.4 m were built on specially designed steel foundations. Model A is regular in plan while model B has significant irregularities. Four additional masses of 600 kg each were placed on the first floor for considering a life load of 2 kN/m². Premium insulation filled clay blocks with excellent mechanical and thermal performance were used. The layer of mortar had a thickness of about 1 mm. A historic record modified to match the Eurocode 8 spectrum was used; at 100% intensity it has a PGA of 0.36g (N-S) and 0.32g (E-W). That signal was applied also scaled to 12.5% or 25% of the full one. The models were tested in eight stages with consecutive uniaxial shaking seprately in the two directions at the first stage, followed by biaxial shaking at the next stage, and so on. For each load level several shakes with increasing intensity were performed to reach the 100% intensity, giving a total number of 62 shakes for model A and 54 shakes for model B. Both models had heavy damage at the 100% intensity level and collapse was imminent. That intensity exceeds the design PGA by a factor of 2.0 to 2.5.

Assessment of innovative solutions for non-load bearing masonry enclosures

RC frames with masonry infills were tested under biaxial loading inducing both in-plane and out-of-plane response of the infills. At a first phase (Phase 1), a two-storey, 1:1.5 scaled, one-by-one-bay RC frame building was tested. The infills are built with single leaf clay bricks and a reinforced mortar coating (with wire mesh reinforcement placed within the mortar coating on both sides of the infill walls and anchored to the RC frame and masonry units). Additional masses were attached to the walls to respect Cauchy-Froude similitude requirements. A bi-directional artificial ground motion fitted to Eurocode 8 type 1 spectrum for Lisbon was applied at three increasing amplitude levels. There was no noticeable damage after the first two levels but the last one caused considerable cracking at the corners around the infill openings. Removing the reinforced mortar coating, the infill walls were found overall undamaged but detached from the RC frames. It was apparent that the reinforced masonry specimens have a clearly superior seismic behaviour compared to the unreinforced masonry building, including prevention of out-of-plane collapse of infill walls.

In Phase 2, four full-scale RC plane frames infilled with masonry are tested simultaneously in the in-plane and out-of-plane direction. Both unreinforced masonry infills and infills with horizontal reinforcement between masonry units were tested, with and without reinforcement in the mortar coating. The testing setup simultaneously uses the shaking table, one reaction wall and a novel Testing device for Innovative Masonry infills (TIM). This test setup was specifically conceived and designed for these tests; it consists of a stiff steel caisson 3D frame which moves rigidly with the shaking table; it is fixed to the specimen's top beam in the transverse direction, while a system of rollers allows independent motion in the longitudinal direction. The in-plane and out-of-plane motions represent the dynamic response of narrow-band frequency content, in a typical upper storey frame panel of a RC building. The in-plane motion enforces an inter-storey drift history on the frame by restraining the upper beam movement, which is prestressed for withstanding push-pull actions, and by imposing the displacement of the shaking table on the lower beam. All beam-column joints are free to rotate in the plane of the infill. The out-of-plane motion consists of a rigid-body vibration of both the upper and lower beams, reproducing the storey absolute accelerations, inducing high-frequency inertia forces perpendicular to the masonry panel and local vibration of the infill wall. This shaking table motion is transmitted to the top beam through the rigid steel caisson. This testing procedure and TIM itself will be submitted by LNEC for a utility patent.

High-performance composite-reinforced earthquake resistant buildings with self-aligning capabilities

Shake table tests were carried out on laminated timber frames with 3D moment connections. One single-storey full-scale frame and a 1:3 scaled model of a 3-storey moment frame were tested (Fig. 5(a)). Three types of beam-column connection were subjected to preliminary quasi-static cyclic loading at full scale, to study their hysteretic behaviour, energy dissipation and failure mode and develop moment-rotation curves, from which the internal moments during the shake table tests could be back-calculated, using digital images of the rotation of beam-column connections during shake table testing: a) The rigid connection, with self-tapping steel screws (Fig. 5(c)), where the energy dissipation takes place; this type of connection was applied to the one-storey full-size frame tested on the shake table. b) The frictional connection (Fig. 5(d)), consisting of a vertical, trapezoidal-shaped kerf metal plate embedded at mid-width of each beam, fixed to the beam via self-tapping screws, a T-shaped steel plate fixed to the column face with four bolts, and two bolts connecting the kerf plate to the T-shaped plate, tightened to allow slippage and friction between them; to increase the energy dissipation by friction, a steel plate was added at each bolt end, between the metal plate and the bolt nut. The beams and columns were reinforced near the connection with unidirectional Glass-Fibre fabric, epoxy-glued to the member lateral surface. This type of connection was found to have the best energy dissipation capacity and other hysteretic features. A connection similar to the one above was also used, but without the frictional joint between the kerf plate and the T-shaped plate, relying only on the steel connection for energy dissipation (Fig. 5(e)). It was found to have pinched moment-rotation behaviour and energy dissipation inferior by a factor of about 2; so, it was not chosen for the shake table tests. The one-story full-size frame (Fig. 5(b)) sustained triaxial seismic motions with horizontal peak ground acceleration (PGA) up to 1.25g. Under a motion with a PGA of 1.43g, one of the columns failed in shear next to the rigid connection with self-tapping screws. The 3-storey 1:3 scaled frame went unscathed through triaxial seismic motions with Root Mean Square acceleration in the horizontal directions of up to 1.0g, with vertical PGA of 0.2g. It failed under a biaxial motion with PGAs in the two horizontal directions of 2g.

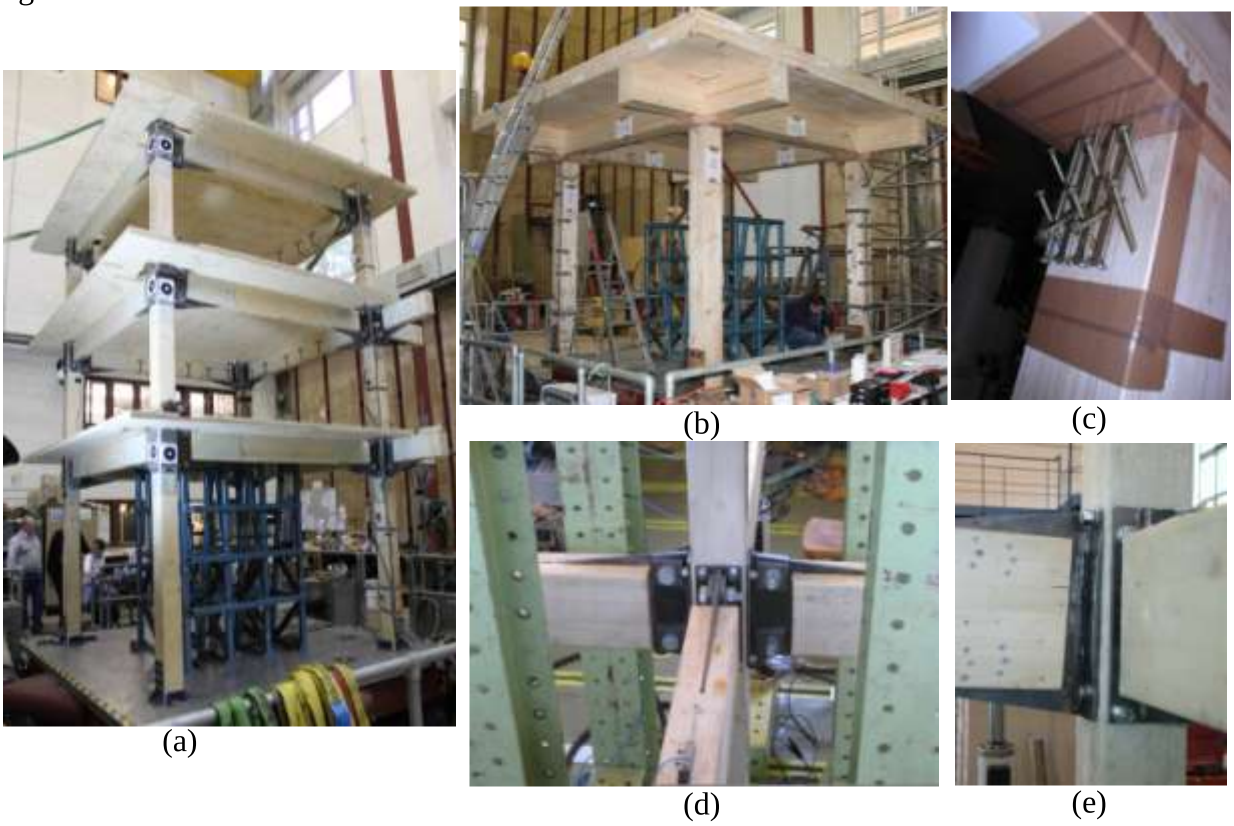


Figure 5 (a) 3-storey 1:3 scaled model on shake table; (b) full-scale one-storey test frame; (c) rigid beam-column connection with self-tapping screws; (d) beam-column connection with frictional joint in preliminary 3D cyclic test; (e) connection as in (d) but without the frictional joint.

Seismic behaviour of L- and T-shaped unreinforced masonry shear walls including acoustic insulation devices

It can be difficult to verify the seismic stability of masonry buidings according to the Eurocodes by considering the walls only in the earthquake direction, especially if these walls are not subjected to a high compression due to gravity loads (e.g., for one-way floors). It is thus necessary to account also for transverse walls acting as flanges. However very few experimental tests are available to support design methodologies based on this principle. Very strict acoustic requirements are also mandatory for buildings with apartments. Efficient acoustic isolation techniques have been developed, but their consequences on the building stability under horizontal actions are unknown. Two sets of tests focusing on complementary aspects of this concept are carried out. The first set aims concerns walls on a 10 mm thick rubber layer for acoustic purposes. Four such walls were tested, two of them with, and two without acoustic rubber mat. The height is 1.8 m, the thickness 140 mm, and the length 0.75 m or 2.1 m. The rubber mats were found to significantly modify the stiffness, frequency and damping of the wall and to change the characteristics of the rocking motion under seismic action. The second test series concerns two flanged walls: T-shaped or L-shaped, coupled by a lintel, considering different load conditions (i.e. gravity loads on the longitudinal shear walls, on the transverse walls or on both). The torsional behaviour was also investigated.

Assessment of the seismic behaviour of flat-bottom silos containing grain-like materials

Several shake table tests were performed with different heights of ensiled material to simulate silos of different aspect ratios and different magnitudes of grain-wall friction, to verify analytical findings regarding the actions induced by grain like material on the walls of flat-bottom silos. The specimen is a 1.2 m diameter, 1.2 m tall, 3 mm thick poly-carbonate container. Polycarbonate, with E = 2.3 GPa, was used to increase the strains. A ring on top of the specimen prevents local deformations. The instrumentation measures: (i) table, structure and grain accelerations at different locations; (ii) structure deformation at different levels; (iii) displacement at the top; (iv) local pressures exerted by the grain on the walls. Inputs applied to the table were: (a) white noise to determine the dynamic properties; (b) low frequency sinusoidal input to simulate time constant horizontal accelerations (0.5- 2Hz); (c) historic records. By varying the grain-wall interface properties and the height of the ensiled content, three different configurations have been tested: (i) smooth silo walls (grain-wall friction coefficient of 0.30) filled with Ballotini glass up to a height of 1.2 m; (ii) roughened walls (friction coefficient of 0.45) filled up to a height of 0.6 m; (iii) as in (ii) but filled up to a height of 1.2 m. The last one was tested under sinusoidal input, along the horizontal direction only. Peak acceleration profiles up the silo walls under different 1 Hz sinusoidal inputs are almost constant vertically for table accelerations less than 0.35g (very low amplification). A slight amplification of around 1.2 can be noted from the bottom to the top of the silo at accelerations above 0.35g. At different input frequencies and accelerations, the experimental bending moment at the base of the silo is much closer to the value given by analytical theory than to the two values (simplified and accurate procedures) given by the Eurocode 8 rules, but indeed lower than both the analytical and the Eurocode 8 predictions. The results indicate that in all cases the effective mass is lower than the Eurocode specification. At PGAs up to 0.35g, the analytical formulation provides an improved estimate of the inertial force imposed on such structures by their contents.

Study of multi-building interactions and site-city effect through an idealized experimental model

The common earthquake engineering practice does usually consider the substratum in cities, but disregards the resonant 'surstratum' made up by the city itself. Both numerical and analytical results suggest that global soil-structure interactions, i.e. Site-City effect, occur and can be significant, especially when the fundamental frequencies of the soil and of the heaviest buildings coincide. The aim of this study was to investigate experimentally this phenomenon through an idealized specimen on the shaking table and compare the resulting data with two theoretical models. A polyurethane foam block with 1 m dimensions stands for the soil layer and 37 parallel vertical aluminium sheets stand for the buildings. Other configurations have also been tested with less dense cities, irregular distributions and cities with two different resonators. The buildings can bend and resonate with out-of-plane excitation, but remain quasi-static with in-plane excitation. This enables to show the differences between resonant and inert masses. The specimen provides a good matching between the fundamental frequencies of the foam block and of the aluminium resonators. In the non-resonant direction, the system acts classically as a layer with added inert mass on top. In the resonant direction, global interactions split the resonance peak into two peaks that favour beatings, reduce significantly both surface and the resonators' motions at their common fundamental frequency, decrease the amplitude of the resonance peaks and induce longer signals with slower decreasing codas. These specific features have been recovered by both analytical and numerical models giving a qualitative and quantitative agreement with experimental results and a quasi-perfect agreement with one another.

Experimental investigation of dynamic behaviour of cantilever retaining walls

The dynamic behaviour of cantilever retaining walls founded on compliant base under earthquake action was explored by means of 1-g shaking table testing on scaled models. The program encompassed different combinations of retaining wall geometries, soil configurations and input motions (white noise, sine dwells and actual recorded motions). The systems were tested dynamically using a large Equivalent Shear Beam container of dimensions 4.8 m long by 1.15 m high by 1m wide, installed on the shaking table. The response analysis of the systems aimed at shedding light onto the salient features of the problem, such as: (1) the magnitude of the soil thrust and its point of application; (2) the relative sliding as opposed to rocking of the wall base and the corresponding failure mode; (3) the importance/interplay between soil stiffness, wall dimensions, and excitation characteristics, as affecting the above. The experimental findings confirm the predictions of theoretical analysis, with reference to the failure mechanisms and the critical yield accelerations of the system. Pseudo-static stability analysis proved to be adequate for both harmonic and earthquake excitation, although the latter relates to conditions closer to the assumptions of the pseudo-static analysis, i.e., the uniform distribution of the acceleration and the "rigid block" response of the backfill. The responses of the various wall configurations confirmed the equivalent footing analysis of wall stability and highlighted the importance of a proper design of walls founded on a compliant base with respect to sliding and rocking. The experimental results were in good agreement with the theoretical models and are expected to be useful for the better understanding and the optimization of earthquake design of this particular type of retaining structure.

Dynamic behaviour of soils reinforced with long inclusions (piles)

The dynamic response of soil-pile-group systems is modelled both analytically, using homogenisation theory, and physically, using a shaking table to test a soft elastic material periodically reinforced by vertical slender inclusions. A large soil/pile stiffness contrast is shown to lead to full coupling in the transverse direction of the pile bending with the soil in shear. Analytically predictions capture the important characteristics of the experimentally observed response. The shear/bending analytical modelling approaches provide a simple way to design and describe a soil/piles system under ground motions. The physical model was a 2.13 m by 1.75 m by 1.25 m tall block of soft linear-elastic polyurethane foam (E_m = 54 kPa) and reinforcement of mild steel tubes with 12.7 mm outside diameter and 3.25 mm wall thickness and perfect adherence at the interface. 35 1.3 m long inclusions were used on a seven by five grid at 250 mm centers. From the boundary conditions (e.g. clamped, free), the modes and eigen-frequencies are found. Comparisons between test and theory were based on the first mode response of the system. Measurements (through strain gauges and accelerometers, under white noise or harmonic excitation) were in accordance with theory. Bending effects were clearly evidenced and the shear/bending model captured well the observed strain distribution and fundamental frequency.

Soil-pile-structure seismic interaction

The soil-pile-structure interaction (SSPSI) problem is studied by shaking table tests. The kinematic interaction developing between the pile and soil cannot be simply reproduced in the field; conversely it is generally straightforward to reproduce experimentally the inertial effects on piles. Laboratory investigation are essential to understand the response of single piles and pile groups. Centrifuge and 1-g shaking table tests have advantages and disadvantages. A 1-g apparatus, like a shear stack on a shake table, as adopted in this study use a larger and more reliable physical model, which allows detailed measurements of pile response and combinations of soil profile, pile-head boundary conditions and superstructure features. It is possible to do a wide set of tests at reasonable cost. The tests were carried out on a group of piles, with or without pile caps and a simple oscillator on pile top. The loading conditions include white noise, sinedwells and earthquake records. The tests investigated various aspects of SPSI, such as the natural frequency of the system (both horizontal and vertical), the natural frequency and damping of embedded piles, the horizontal and vertical soil-pile kinematic interaction and foundation-structure interaction. The response of two different configurations excited with the same input shows that the envelope of the accelerations in the free-field condition versus the depth is the same for the two tests considered. The envelope of bending moments along instrumented piles shows typical effects of inertial interaction due to the simple oscillator on pile top; these effects are more important in the free-head configuration than in the short cap one; the latter exhibits a redistribution of bending moments due to the connection between the piles.

Centrifuge modeling of dynamic behaviour of box–shaped underground structures in sand

The main objectives are to evaluate and understand the dynamic behaviour of box-type underground culverts, to study the effects of the flexibility ratio and of the shear strain on the dynamic response of box-type culverts and to examine the deformation of the culvert by considering the nonlinear behaviour of soil and the dynamic soil-structure interaction. Twenty six accelerometers were used in the centrifuge tests: two on the upper and lower parts of the culvert model, to assess the racking deformation; others were buried in the soil or placed on the ESB box. The box culvert was buried in Fontainebleau sand at a depth of 7.5 cm. Sand pluviation was used to obtain a consistent and uniform soil density for the dynamic centrifuge tests. Dry Fontainebleau sand was pluviated into the ESB box using the IFSTTAR automatic hopper. Density control boxes were placed in the box to measure relative density. Cone Penetration Tests (CPT) were conducted to check the uniformity and repeatability of the sand specimen. The average settlement of the sand after shaking was about 6.5 mm in the model, which corresponds to 260 mm in the prototype. Accelerometers and extensometers were used to measure culvert deformations. Acceleration transducers at the upper and lower parts of the culvert gave estimates of the racking deformations. Five pairs of horizontal extensometers were mounted on the side walls at different heights to measure lateral deformations. Four pairs of diagonal extensometers were placed diagonally to evaluate the racking deformations. Although cyclic deformations at the left and right sidewalls were not perfectly equal, the records were reasonably consistent. Deformations increased from the bottom slab to the upper slab of the culvert. The measurement of displacement mode on the culvert sidewalls showed the expected opposite phase between the reciprocal extensometers.

Studies of nonlinearity in soils using advanced laboratory-scaled models
This project focused on the centrifuge modeling of seismically-induced strains vs. stratigraphic features, namely the presence, thickness and location of clay levels representing the alluvial deposits of the Tiber River in the historical centre of Rome. Centrifuge modeling with a dynamic action was associated to the numerical simulation of non-linearity by 1D-1C and 1D-3C approaches. Four samples were tested at reduced scale in centrifuge, representing two homogeneous soil columns (clayey and sandy column respectively) and two heterogeneous soil columns, including a clay level between two sand beds. The maximum expected seismic action in Rome was simulated at the shaking device as: i) a natural time history, ii) an equivalent sinusoidal signal and iii) a multi-frequency equivalent signal (LEMA_DES approach). The sand layers were fine NE34 Fontainebleau sand deposited by air pluviation. The clay layers were prepared from a Speswhite clay slurry consolidated first under a jack pressure and a complementary consolidation phase in flight before the shakes. The saturation liquid was water added with HPMC methyl-cellulose derivate, with viscosity as near as possible to 55.55 cSt. The multilayer profiles were prepared as follows: air pluviation and saturation of bottom sand layer, pre-consolidation of the clay layer in an independent container and transfer on top of the bottom sand layer with the help of a suction device, complementary pluviation and saturation of the top sand layer. Two arrays of accelerometers and one pore pressure array measured soil responses. The positions of sensors were adjusted to look for transitions of soil stiffness. The measured soil response was compared to theoretical predictions.

Seismic behavior of shallow rectangular underground structures in soft soil
In this project the seismic response of shallow rectangular tunnels was studied by centrifuge testing, under a centrifuge acceleration of 40g. Well-documented experimental data was recorded for a wide set of soil-tunnel systems, allowing a better understanding of the seismic behavior of underground structures as affected by soil-structure relative flexibility, soil-tunnel interface properties, soil saturation and amplitude of excitation. Seven centrifuge test cases were carried out in total, by combining flexible or rigid tunnel sections, smooth or rough soil-tunnel interface and dry or saturated Fontainebleau sand N34 with ID = 70%. Novel techniques for the sand pluvation, the model saturation and the waterproofing of the tunnel sections were used for the models. Each soil-tunnel system was excited by a real record scaled to a PGA of 0.1g, 0.2g and 0.3g, followed by a sine wave at 0.3g. Cone Penetration Tests (CPT) checked the soil preparation repeatability and measured soil settlements during and after the successive shakings. A large number of recording devices was employed to record soil-tunnel response: miniature piezoelectric accelerometers in vertical arrays within the soil or attached to the tunnel section and the ESB container, displacement sensors to record the surface ground settlement, pore pressure sensors to measure pore pressure dissipation, for the saturated cases. Specially designed extensometers were used to record the racking distortions of the tunnel section. The acquired datasets offer valuable experimental evidence on fundamental aspects of seismic response of soil-tunnel systems. Representative soil acceleration and tunnel deformation recordings provide insight to the soil-tunnel interaction mechanism and the tunnel racking distortion, as affected by the intensity level of the input motion.

Experimental verification of shallow foundation performance under earthquake-induced liquefaction

This project focused on the seismic performance of square footings on a stratified soil profile commonly encountered in the field, namely a thick liquefiable sand layer overlaid by a thin over-consolidated clay crust. The scope of the tests was to verify the beneficial effect of the surficial non-liquefiable layer on the dynamic and post-shaking response of the footing. Furthermore, the tests aimed at exploring the existence of a critical thickness of the clay crust, beyond which subsoil liquefaction does not affect the overall foundation performance. For this purpose, different thicknesses H of the clay crust were parametrically used, from H = 0.65B to 1.5B, with B being the footing's width (3 m in the prototype). Each test was performed in three stages. The centrifugal acceleration was initially raised to 50g, in steps of 10g, allowing adequate time for the consolidation of the clay layer. A harmonic excitation was consequently applied to the base of the equivalent-shear-beam container. During this stage, excess pore pressures developed in the sand layer, resulting in the accumulation of seismic settlements of the square footing. Immediately after the earthquake stopped, the footing was pushed down using a vertical actuator via a load cell. Both vertical load and displacements were measured. The centrifuge tests were the first ones of such type in the world. The timing of deployment of the vertical actuator, immediately after the earthquake loading finishes, i.e. before earthquake-induced excess pore pressures dissipate, was critical. Analyses with the Finite Difference Code FLAC3d were carried out, in order to replicate the centrifuge tests and identify the basic interaction mechanisms which underlay the footing's response. The outcome will help to assess the vulnerability of buildings founded on clay layers above a liquefiable stratum to earthquake-induced liquefaction, and to establish performance-based design criteria in terms of footing settlements and degraded post-shaking static bearing capacity.

Shallow foundations in seismic liquefaction: Study of level, mitigation of effects

Centrifuge tests at 50-g investigated remediation methods for shallow foundations on liquefiable soils. Shallow foundations rested on liquefiable soils with a number of remediation schemes, involving soil densification and drainage, to reduce foundation settlements. Model shallow squared foundations were placed on top of the liquefiable layer, imposing on the ground pressures of 58 kPa and 95 kPa at prototype scale. The viscosity of the fluid was chosen to accomplish viscosity scaling and eradicate the time conflict in dynamic and flow phenomena in centrifuge modelling. The experimental findings show that hybrid mitigation techniques, using both densification and high capacity vertical drains through the entire liquefiable layer, are quite promising for the reduction of settlements under the foundation. The results show that, as expected, hybrid techniques combining narrow densified zones with vertical drains mitigate the excess-pore-pressure developed under footings during earthquake shaking, much faster than when no drains are used.

Seismic performance of propped flexible retaining walls embedded in saturated sand

Retaining structures can experience serious damage when exposed to moderate to strong earthquakes, with both failure of structural elements and large permanent displacements of the walls. An understanding of the dynamic behaviour of retaining structures and adequate design procedures are vital for the control of seismic induced displacements and the limitation of damage to the surrounding buildings. Four centrifuge tests on reduced scale models of pairs of flexible retaining walls embedded in saturated sand were carried out, at a centrifuge acceleration of 40g. Two tests were performed on cantilevered walls (CWU), and two on walls with one level of props near the top (PWU). Models were prepared using loose (D_r = 40%) and dense (D_r = 80%) Leighton Buzzard sand and were contained in a laminar box. The steady state hydraulic condition was hydrostatic at dredge level. The pore fluid was Hydroxyl Propyl Methyl Cellulose (HPMC), with viscosity that is 40 times the viscosity of water, thus making the time scaling factors for inertial effects and pore pressure dissipation the same. Each model was subjected to two or three earthquakes with the same frequency and increasing peak acceleration. Instrumentation measured horizontal displacements of the walls, settlements of the model surface, accelerations and pore water pressures at various locations, bending moments in the retaining walls and axial forces in the props. The results show a significant increase in pore fluid pressure during the earthquakes, both in dense and loose sand, changes in the bending moment distribution during the earthquake and important attenuation of acceleration within the soil for the tests in loose sand.

Investigation of seismic behaviour of shallow rectangular underground structures in soft soils

A series of dynamic centrifuge tests were performed on flexible square tunnels embedded in dry sand, to further knowledge on the dynamic response of this type of structures. Two tunnel models were tested, a rigid and a flexible one, with the latter collapsing during the test. An extensive instrumentation array was utilized to monitor the soil-tunnel response: miniature accelerometers, pressure cells and position sensors, in addition to strain gauges that recorded the strains within the tunnel lining. The horizontal acceleration recorded at several locations in the soil was generally amplified towards the surface; this amplification was affected by the presence of the tunnels. Vertical acceleration-time histories recorded on the sides of the model's roof slabs were generally out of phase, indicating a rocking mode of vibration for the tunnels. Three distinctive stages were identified for the earth pressures evolution; a transient stage followed by a steady-state stage and finally a post-earthquake residual stage. The residual response was significantly amplified by the flexibility of the tunnels. Residual values were reported for the lining dynamic bending moments and the axial forces, due to soil yielding and densification during shaking. The collapse of the flexible tunnel started during the swing up of the centrifuge (increase of the gravity loads) with buckling of the roof slab-right corner. This resulted in larger compressive loads on the left side-wall of the tunnel, that finally buckled during the subsequent final earthquake. P-delta effects also affected the behavior. Representative test cases were numerically analyzed by means of full dynamic analysis of the coupled soil-tunnel system. The numerical predictions are compared to the experimental data to validate the effectiveness of the numerical models. The final calibrated models are used to further investigate the dynamic response of embedded rectangular structures and validate available design methods used by industry.

Socio-Economic Impact, Dissemination and Exploitation of Results
(10p maximum)

Socio-Economic Impact

As a preamble to the socio-economic impact of the project, an excerpt from the conclusions of the "SERIES Concluding Workshop" in May 2013 is quoted below:

- *SERIES has been the largest project in Earthquake Engineering within FP7 (2007-2013) in terms of budget, partnership and number of researchers involved. Its emphasis has been on testing and further developments of experimental techniques. It essentially encompassed the entire European S & T earthquake engineering community, by bringing together 23 RTD partners from 11 European countries and 210 external users of SERIES's best testing facilities from 23 European countries. In this way it significantly contributed to the integration of the European S/T earthquake engineering community. A prime example of the benefits from co-operation across national borders and integration is Eurocode 8, which became a reality thanks to the common efforts in the past of this S/T community.*

One point noted in the extract above is that SERIES was the prime contribution of FP7 to Earthquake Engineering and, through it, to the reduction of seismic vulnerability of the existing and new construction works in Europe. This reduction will be major socio-economic impact of the project in the medium to long term, and will be made possible through the improvements in, and the wider dissemination of S & T knowledge brought about by SERIES. The second point raised in the above excerpt refers to Eurocode 8: "Design of structures for earthquake resistance", which on one hand constitutes the prime technical means for the seismic protection of new and existing construction works in Europe and, on the other, reflects the best S & T knowledge available to the European Earthquake Engineering community. In fact, the first instance and way where the new knowledge produced by SERIES will be used, will also be the most effective in enhancing the seismic protection of the new and the existing construction: the revision of EN Eurocode 8: "Design of structures for earthquake resistance", which is due to be launched in 2014, in the framework of the evolution of the EN Eurocodes towards their second generation (see "Exploitation of results" Section below for details).

The project's high point was the Transnational Access (TA) activities. They have provided to talented and resourceful European researchers the opportunity to access and use in-person the high-performing unique research infrastructures they need for their research, irrespective of the location of the infrastructure. Besides, thanks to the large number of beneficiaries from high seismicity European countries (including Balkan Member or Associated States and Turkey) and the project's four workshops which were organised there, it has targeted promising young users from those countries, which are most in need of the RTD opportunities offered by SERIES. Besides, as pointed out in the conclusions of the SERIES "Concluding Workshop":

- *The TA projects not only gave the opportunity to researchers from the outside to use the advanced experimental facilities and knowhow in Europe's best seismic RIs, but also allowed the flow of fresh ideas to the facilities and the interaction with high-level researchers, to the benefit of both sides.*
- *The involvement of industry in TA projects is remarkable, with potential benefits to innovation in seismic design practice in Europe.*

Through the transfer of knowhow and expertise from the best and largest seismic research infrastructures (RIs) established in the most technologically advanced but lower seismicity EU Member States to up-and-coming RIs in high seismicity but less technologically advanced European countries, SERIES will help the latter emerge in the medium to long term as seismic RIs of pan-European interest.

In the medium to long term SERIES will enhance the competitive edge of European construction firms and engineering services in overseas seismic markets, by establishing Europe as a world leader in earthquake engineering research, at a par with the US and Japan.

Dissemination activities

The "normal" way of disseminating S & T results, namely papers in Journals and Conferences, has been used and will be used further to disseminate the project's foreground. It is notable that the mainly Co-ordination and Support character of SERIES (even its JRAs, which are RTD activities by name, in essence provided Support to the experimental research infrastructures) does not lend itself to prolific production of S & T papers. In spite of that, SERIES has already produced an impressive volume of Journals and Conference papers.

Hardbound volumes of Proceedings of three SERIES Workshops, organised in:

- Ohrid (MK), in September 2010 - in conjunction with the 14th European Conference on Earthquake Engineering;
- Istanbul, in February 2012;
- Ispra (IT), in May 2013 - jointly with the US Network for Earthquake Engineering Simulation (US-NEES).

have been published (or will soon be) by Springer, as part of its reputed series in Geotechnical, Geological and Earthquake Engineering. Their details are:

- "Role of Seismic Testing Facilities in Performance-based Earthquake Engineering" Springer, ISBN 978-94-007-1976-7, Oct. 2011 (M.N. Fardis, Z. Rakicevic, eds), 384p.
- "Seismic Evaluation and Rehabilitation of Structures" Springer, ISBN 978-3-319-00457-0, August 2013 (A. Ilki, M.N. Fardis, eds), 455p.
- "Experimental Research in Earthquake Engineering", Springer, September 2014 (expected) (F. Taucer, ed), circa 600p.

Six training courses were organised on advances in testing and good operation practice in RIs:

- A preparatory course on experimental testing and theoretical background, at EUCENTRE, Pavia (IT) in March 2010, with 31 attendees.
- A course on PsD Testing, at JRC, Ispra (IT) in Nov. 2010, drawing 21 attendees.
- A seismic qualification course at UNIVBRIS, Bristol in Jan. 2011, with 17 attendees;
- A course on physical modelling in centrifuge tests, at IFSTTAR (in collaboration with UCAM), Nantes (FR) in March 2011, with 16 attendees;
- A course on shake table testing, including data reduction and interpretation, at CEA, Saclay (FR) in Jan. 2012, drawing 22 attendees;
- Another course on shake table testing, with hands-on practical application, at LNEC, Lisbon, in Sept. 2012, with 8 attendees

Other means of dissemination are:

- A distributed (virtual) database of experimental data and all supporting documentation, from test campaigns (past or recent) in the SERIES RIs and from the literature; with new data to be uploaded in the future, it aspires to become the world's largest repository of seismic testing data; it is accessed through the Data Access Portal (http://www.dap.series.upatras.gr/).

- The public pages of the project's web portal http://www.series.upatras.gr, to be maintained well beyond the end of the project and giving, among others:
  - The presentations at the four SERIES Workshops (http://www.series.upatras.gr/workshops) and the six training courses, (http://www.series.upatras.gr/training_courses) as well as the lecture notes and handouts of the courses;
  - The project Deliverables (http://www.series.upatras.gr/public_documents);
  - The detailed technical reports of the TA projects (http://www.series.upatras.gr/TA_projects) and a brochure summarising all of them (http://www.series.upatras.gr/node/743);
  - etc.
- Telepresence in tests which have been or will be carried out at the project's RIs, live (online) or off-line.
- A discussion forum (http://www.series.upatras.gr/forum/)
- etc.

Exploitation of Results

As a preamble to the plans for exploitation of the project results, excerpts from the conclusions of the "SERIES Concluding Workshop" in May 2013 are quoted below:

Benefits from SERIES to European integration

- *SERIES ... essentially encompassed the entire European S & T earthquake engineering community, ... In this way it significantly contributed to the integration of the European S/T earthquake engineering community. A prime example of the benefits from co-operation across national borders and integration is Eurocode 8, which became a reality thanks to the common efforts in the past of this S/T community.*

RTD in Earthquake Engineering

- *In past FPs seismic testing and Transnational Access to large seismic testing facilities were the focus of separate projects, while concurrent networking or RTD projects with different partners – informally interacting with the infrastructures projects – served the prenormative RTD needs and priorities for earthquake protection and resistance, ...*
- *As in the past, future FP programs should emphasise problems more central to earthquake resistance and protection .... The upcoming revision of Eurocode 8 will profit from the outcomes.*

According to the first phrase quoted above, SERIES essentially is the European S & T community in Earthquake Engineering. So, exploitation of the SERIES RTD results by the community is equivalent to exploitation by the SERIES Consortium. The phrases underlined above further show that, in the eyes of this community, Eurocode 8 has top priority as the beneficiary of European RTD in earthquake engineering. Indeed, EN Eurocode 8 is seen as the main – if not the only – means to improve earthquake protection in Europe in the short-to-medium term. Accordingly, the improvement of Eurocode 8 takes top priority in the exploitation plans of SERIES.

In May 2010, the Enterprise and Industry Directorate-General (DG ENTR) of the European Commission (EC), which defines the EU policies for the construction sector and supports standardization, sent Programming Mandate M/466 EN to the European Committee for Standardisation (CEN) concerning the Structural Eurocodes. The purpose of the mandate was to initiate the process of further evolution of the Eurocode system, incorporating both new and revised Eurocodes, and leading to the publication of the second generation of EN Eurocodes. CEN replied to this mandate in June 2011. In December 2012, the EC sent further Mandate M/515 EN Structural Eurocodes, inviting CEN to develop a detailed standardisation work programme using the reply to mandate M/466 as a basis.

In reply to Mandate M/515, CEN Technical Committee CEN/TC 250: "Structural Eurocodes", sent to the EC Document N 993 of CEN/TC 250, dated 29/05/2013 and titled: "CEN/TC 250 - Response to Mandate M/515 EN: Towards a second generation of EN Eurocodes". This is a fundamental document, setting out TC 250's proposed work programme, together with additional supporting information. In Annex 1 "Detailed Work Programme" of the document, the programme for the revision of EN 1998 "Eurocode 8: Design of Structures for Earthquake Resistance" is set out.

Below are reproduced (in italics) the various parts of that programme, slightly abridged. Each part is followed by the specific foreground of SERIES which will be exploited to serve the specific goals set out for Eurocode 8 by CEN/TC 250 Document N 993 "Response to Mandate M/515".

Evolution of EN 1998-1 “General, Seismic action, Rules for buildings"

1. European Seismic Zonation and definition of the Seismic Action

Background: *In Part 1 of EN-Eurocode 8 (EN 1998-1:2005), the seismic zonation and the spectral shape of the seismic action for design are Nationally Determined Parameters (NDPs), defined in the National Annexes. EN 1998-1:2005 advanced harmonization by establishing a "standard shape" of the design spectra and the anchoring variable for the definition of the national seismic zonation maps.*

Goal: *Further harmonization is needed in the revision of EN 1998, by redrafting of Section 3 of EN 1998-1 (Ground conditions and Seismic action), towards a harmonized seismic zonation, but still enabling the Member States to establish their own safety levels at different performance levels and for different types of structures (importance classes).*

SERIES foreground to serve the above goal:

Outcome of Task JRA3.1:

- Proposal for a new set of amplification factors for Eurocode 8 soil classes and a new classification system with the corresponding normalized acceleration spectra and amplification factors: It has been developed mainly by AUTH, and represents a major improvement over the present Section 3 of EN 1998-1.

2. Displacement based design

Background: *The seismic action corresponds to the application of displacements rather than of forces to the structures. For practical reasons, the reference seismic design approach in EN 1998-1 (as in practically all other current seismic codes) is still force-based, with correction for the nonlinear response via the behaviour factor. Complementary to this reference approach, EN 1998-1 already foresees and allows Displacement-based design using nonlinear static (pushover) analysis. However, the specific safety verifications to be made are not yet fully presented. The “demand side” is dealt with in Informative Annex B, describing the determination of the target displacements for pushover analysis. The “supply side”, related to the deformation capability of elements and structures, is not yet included.*

Goal: *Development and codification of displacement-based design for new buildings. Annex B of EN 1998-1 will be fully revised and extended to cover both the demand and the supply sides of safety verifications. Profit shall be taken from what is* *available in EN 1998-3, namely the verification criteria for the yielding and ultimate deformation capacity of structural members and the whole structure.*

SERIES foreground to be exploited:

Outcome of Task NA1.5:

- Database of tests of RC beams, columns and walls and of other tests residing with the SERIES beneficiaries: As it is public via the SERIES DAP (Data Access Portal), it can be used, not only by the SERIES beneficiaries themselves, but by any researcher in Europe, to develop the missing element for displacement-based design, namely the "supply side", i.e., the deformation capability of elements and structures.

3. Steel and Composite (steel-concrete) buildings

Background: *The European Convention for Constructional Steel Works (ECCS) has prepared the document "Assessment of EC8 Provisions for Seismic Design of Steel Structures", where it lists a number of issues regarding Section 6 of EN 1998-1 that, in their view, require clarification or further development. The intention is to evaluate the proposals made by ECCS for such revision and, whenever agreed, improve and update these Sections of EN 1998-1, bringing them up to date with the more recent advances in seismic design of steel and composite buildings.*

Goal: Updating of Section 6 (Specific Rules for Steel Buildings) and 7 (Specific Rules for Composite Steel-Concrete Buildings).

SERIES foreground to serve the above goal:

TA projects whose outcomes can directly serve the above goal:

- "Full-scale experimental validation of dual eccentrically braced frame with removable links"
- "Improved European design and assessment methods for concentrically-braced frames".

4. Timber buildings

Background: *Section 8 of EN1998-1 on timber buildings was changed very little in the conversion from the ENV stage. Hence, its contents are outdated and need updating. Aspects to be added or updated are:*

- *General re-evaluation of building typologies and values of the behaviour factors;*
- *Capacity Design rules, including overstrength factors of ductile connections;*
- *Definition of interstorey drift limits for performance-based design;*
- *Provisions for wood-based materials, such as cross-laminated panels (xlam) and oriented strand boards (OSB), and some fasteners;*
- *Inclusion of rules for the design of buildings with composite lateral load resisting systems (for instance timber wall panels with concrete cores or steel bracings;*
- *More detailed rules for the design of shear walls and horizontal diaphragms.*

The aim is to bring Section 8 up to date with the state of the art for the seismic design of timber buildings, incorporating the results of recent research. This shall improve the conditions for the use and exploration of the intrinsic favourable characteristics of timber with regard to seismic actions.

Goal: Thorough updating of Section 8 (Specific Rules for Timber Buildings) to incorporate the more recent advances in seismic design of timber buildings.

Extension of the building typologies and the wood-based materials covered in this Section.

SERIES foreground to serve the above goal:

TA projects whose outcomes can directly serve the above goal:

- "High-performance composite-reinforced earthquake resistant buildings with self-aligning capabilities"
- "Seismic performance of multi-storey timber buildings".

5. Masonry buildings

Background: *Masonry buildings represent a very large proportion of low rise construction in Europe. EN 1998-1 did not achieve an in depth harmonization of design provisions as for other materials. This is evident from the very large number of Nationally Determined Parameters (NDPs) for masonry buildings, including the values of the behaviour factor (to the contrary of the provisions to other materials).*

Furthermore there have been claims that the present rules for "simple buildings" (mostly presented as NDPs) are disputable and inconsistent with post earthquake field surveys.

Goal: *Improvement of Section 9 (Specific Rules for Masonry buildings) of EN 1998-1 for better consistency with the Sections on other materials and reduction of NDPs (as much as possible accounting for the large variability of masonry units and construction practices prevailing across Europe). The aim is to extend the overstrength ratio concept to masonry (as foreseen for other materials, depending on the system's redundancy), improve the provisions for prevention of out-of-plane collapse of masonry walls and revise in-depth the rules for "simple buildings".*

SERIES foreground to serve the above goal:

TA projects whose outcomes can directly serve the above goal:

- "Polyfunctional technical textiles for protection & monitoring of masonry structures in earthquakes"
- "Seismic behaviour of mixed reinforced concrete-unreinforced masonry wall structures"
- "Full scale testing of modern unreinforced thermal insulation clay block masonry houses"
- "Seismic behaviour of L- and T-shaped unreinforced masonry walls with acoustic insulation devices".

6. Infilled frames and claddings

Background: *Frame buildings with masonry infills are very common in southern Europe. Section 5 of EN 1998-1 already includes design provisions to account for the presence of infills, mainly devoted to avoid their possible detrimental effects on the main structure. However, their beneficial effects (overstrength and energy dissipation) are not yet accounted for. Improvement of the provisions of EN 1998-1 regarding infills could be sought, but the implications of fully exploiting masonry infills in the design of new buildings should be carefully evaluated, since it entails higher complexity of design and stricter quality assurance requirements for the construction of the infills. Additionally the recent earthquakes, namely in l'Aquila (IT), have shown that in many recent buildings where the structure behaved properly, heavy damage in claddings occurred. This suggests that the design provisions of EN 1998-1 for infilled frames should be extended to cover cladding elements and panels, together with other types of enclosures. The aim is to improve the current rules in EN 1998-1 for infilled frames and extend them to claddings. This shall reduce the risk of out-of-plane collapse of this type of elements. Such collapse may be detrimental to the main structure, since it introduces irregularities in its seismic response; it may also* cause *casualties and heavy economic losses.*

Goal: *Re-evaluate fully the implications of the presence of infills for the seismic design of buildings. This should be done in conjunction with the revision of Section 9 on Masonry buildings, in view of some common aspects between the two situations.*

Topics for possible inclusion are the improvement of modeling and of seismic design verifications for infill and cladding panels with and without openings (including the evaluation of strength, stiffness and deformation capacity) and the requirements for the connection to the main structure.

SERIES foreground to serve the above goal:

TA project whose outcome can directly serve the above goal:

- "Assessment of innovative solutions for non-load bearing masonry enclosures".

Evolution of EN 1998-3 "Seismic retrofitting of structures"

1. Buildings

Background: *The growing importance of the sustainable use of construction materials and the need to provide adequate seismic protection to the population increased the relevance of assessment and seismic retrofitting of the very large building stock in the most seismic areas in Europe. This was at the core of the past decision to develop Part 3 of Eurocode 8 in the first batch of Eurocode parts. The field of assessment and retrofitting of structures is relatively new and has evolved rapidly in recent years. Hence some basic concepts and design rules presently in EN 1998-3 require updating to keep it in pace with developments at world level. Aspects to be added or updated are:*

- *Use of confidence factors and knowledge levels; consideration of other uncertainties in the design procedures for assessment and retrofitting;*
- *Use of the concept of Performance levels (in a way coherent with the concept of Limit States generally used in the Eurocodes) should be reviewed to adapt to the specificities of existing structures;*
- *Extension of clauses related to nonlinear analysis, in order to provide a better guidance for its practical application by ordinary designers.*
- *Updating of the current rules of EN 1998-3 related to shear resistance. It should be stressed that the behaviour of elements under large alternate cyclic shear is in many cases the "weak link" in the structures of existing buildings (namely in concrete and masonry) and correspondingly a critical aspect in the retrofitting operation.*
- *More detailed rules for shear walls and horizontal diaphragms.*

In view of the intention to develop displacement-based design rules for new buildings that shall profit of the already existing rules in EN 1998-3, this Task should be given priority and proceed simultaneously.

Goal*: Thorough updating of EN 1998-3 for assessment and retrofitting of buildings.*

SERIES foreground to serve the above goal:

TA projects whose outcomes can directly serve the above goal:

- "Seismic retrofitting of RC frames with RC infilling"
- "Full-scale experimental validation of dual eccentrically braced frame with removable links"
- "Polyfunctional technical textiles for protection & monitoring of masonry structures in earthquakes"
- "Seismic strengthening of deficient RC buildings with ductile post-tensioned metal strips"
- "Improved European design and assessment methods for concentrically-braced frames"
- "Tests of historic architecture retrofitted with energy dissipators".

2. Bridges

<u>Background:</u> *Many bridges in roads and railway networks in Europe were built long before the present knowledge on the seismic performance of bridges was available, not mentioning its incorporation in design codes. Thus the seismic vulnerability of those bridges may be quite high, hindering its safety and the reliability of transportation networks, in the event of a strong earthquake. Interventions to evaluate and to reduce such vulnerability are most appropriate and, to some extent, are already being undertaken at national level by some National Authorities. So, it is proposed to extend the scope of EN 1998-3 (currently dealing only with existing buildings) to cover also seismic assessment and retrofitting of existing bridges. This will create the conditions for a more systematic reduction of the seismic risk associated with bridges at European level, with impact on individual bridges and the transportation network reliability. The use of base isolation and energy dissipation devices in bridge retrofitting will have important impact.*

<u>Goal</u>*: Extension of the scope of EN 1998-3 to cover the assessment and retrofitting of bridges. This Part of EN 1998 will be re-titled as: "Seismic retrofitting of structures". The provisions shall be mostly applicable to concrete and steel/composite bridges. They shall also cover retrofitting of foundations and bearings and introduction of base isolation and/or dissipation devices as part of the retrofitting solution.*

<u>SERIES foreground to serve the above goal:</u>

TA project whose outcome can directly serve the above goal:

- "Seismic vulnerability of old RC viaduct with frame piers. Effectiveness of isolation system".

Evolution of EN 1998-5: "Foundations, retaining structures, geotechnical aspects"

1 Soil-structure interaction

<u>Background:</u> *Dynamic soil-structure interaction may influence substantially the seismic response of structures. So, the consideration of such effects is already required in EN 1998-5 for some specific cases and in all cases of pile foundations. However, the provisions therein are quite generic. There is room to extend and improve them with more practical information to the designer for shallow and deep foundations and for the verification of dynamic base failure. On the other hand there are cases of pile foundations where soil structure interaction may be disregarded. These cases should be identified for ease of use.*

<u>Goal</u>*: Updating of EN 1998-5, including soil structure interaction for shallow and deep foundations (effect of lateral restraint of piles by successive soil layers). Inclusion of specific seismic design provisions for modeling, analysis, dimensioning and detailing of piles. General revision of EN 1998-5 with regard to other geotechnical aspects.*

<u>SERIES foreground to serve the above goal:</u>

Outcomes of Task JRA3.3: GDS

- Extensive compilation of test data on nonlinear cyclic foundation response and detailed identification of nonlinear mechanisms governing foundation response.
- Nonlinear dynamic foundation macroelement, applicable to a large variety of foundation configurations, with numerical implementation alongside a relatively simple calibration procedure, validation on the basis of numerical results of monotonic, cyclic or dynamic tests, and use in several seismic design applications (Incremental dynamic analyses, bridge multi-support excitation etc.).

Outcome of Task JRA3.4: NTUA

- A simplified method for estimation of faulting-induced stressing on structures based on the obtained experimental and numerical results.

TA projects whose outcomes can directly serve the above goal:

- "Study of multi-building interactions and site-city effect via idealized experimental model"
- "Experimental investigation of dynamic behaviour of cantilever retaining walls
- "Dynamic behaviour of soils reinforced with long inclusions (piles)"
- "Soil-Pile-Structure Seismic Interaction"
- "Centrifuge modeling of dynamic behaviour of box shaped underground structures in sand"
- "Studies of nonlinearity in soils using advanced laboratory-scaled models"
- "Seismic behavior of shallow rectangular underground structures in soft soil
- "Experimental verification of shallow foundation performance in earthquake-induced liquefaction"
- "Shallow foundations in seismic liquefaction: Study of level, mitigation of effects
- "Seismic performance of propped flexible retaining walls embedded in saturated sand"
- "Investigation of seismic behaviour of shallow rectangular underground structures in soft soils".

Evolution of EN 1998-4: "Silos, Tanks, Pipelines"

Background: Silos and tanks may be of high cost and in some cases, may pose large risk to the population and/or to the environment in case of failure during a seismic event; their response may involve complex interaction between soil-structure and stored material. The design of a pipeline system through areas with poor and possibly unstable soils may be challenging.

Goal: Thorough updating of EN 1998-4 for consistency with the revised versions of EN 1998-1 and EN 1998-5. Possible transfer of part of the Informative Annexes contents into Normative text.

SERIES foreground to serve the above goal:

TA projects whose outcomes can directly serve the above goal:

- "Assessment of the seismic behaviour of flat-bottom silos containing grain-like materials".
- "Investigation of seismic behaviour of shallow rectangular underground structures in soft soils."
- "Centrifuge modelling of dynamic behaviour of box shaped underground structures in sand".

The following individuals, all with key roles in SERIES, will ensure, via their institutional positions in CEN/TC250 "Structural Eurocodes" and/or CEN/TC250/SC8 "Eurocode 8" for the upcoming revision of EN 1998, that the SERIES foreground will be exploited in the revision:

- M.N. Fardis (UPAT, SERIES co-ordinator): Vice Chairman of CEN/TC250 "Structural Eurocodes"; member of the selection panel of experts for the revision of Eurocode 8.
- E.C. Carvalho (Member of the External Scientific Committee and of the International Advisory Panel for Research Infrastructures in SERIES): Member of

CEN/TC250 "Structural Eurocodes"; Chairman of CEN/TC250/SC8 "Eurocode 8"; Chairman of the selection panel of experts for the revision of Eurocode 8.

- Pecker (GDS, WP Leader of JRA3 in SERIES): Member of CEN/TC250/SC8 "Eurocode 8" and of the selection panel of experts for the revision of Eurocode 8.
- P. Fajfar (UL, Leader of SERIES Task NA1.5): Member of CEN/TC250/SC8 "Eurocode 8" and of the selection panel of experts for the revision of Eurocode 8.
- E. Coehlo (LNEC, Leader of WP7/TA5 and of Tasks NA3.11 and JRA2.3 in SERIES): Secretary of CEN/TC250/SC8 "Eurocode 8".
- A. Plumier (Member of the External Scientific Committee and of the User Selection Panel in SERIES): Member of CEN/TC250 "Structural Eurocodes".
- P.E. Pinto (Member of the External Scientific Committee in SERIES): Member of the selection panel of experts for the revision of Eurocode 8.

In addition, since 2005, DG Enterprise and Industry has granted to ELSA/JRC, via a series of Administrative Arrangements on “Support for the implementation, harmonisation and further development of the Eurocodes” presently lasting till 2015, a key role for:

a) The full implementation of EN Eurocodes, through IT support (Eurocodes website – http://eurocodes.jrc.ec.europa.eu, database of Nationally Determined Parameters, database of background documents, centralised Eurocodes helpdesk), dissemination and training, and facilitation of their practical implementation and use (dissemination of training material and organisation of training events);
b) Promotion of the Eurocodes outside the EU (dissemination of informative and training material, organisation of promotion/training events);
c) Further harmonization and evolution of the Eurocodes (in collaboration with CEN/TC 250 Sub-Committees and Working Groups: analysis of Nationally Determined Parameters, publication of technical and pre-normative reports).

Through its role in c), ELSA/JRC is in a prime position to promote best use of the foreground of SERIES, wherever needed for the revision of Eurocode 8.

Besides the exploitation of the SERIES RTD results by the European S & T community in Earthquake Engineering to improve EN Eurocode 8 in its upcoming first revision, exploitation actions or plans include:

- An EU patent: Application No./ Patent No.12199295.2-1553, Applicant/Proprietor: Robert Bosch GMBH and EU (represented by European Commission), date of filing: 21-12-2012, titled: ‘Hydraulic drive for fatigue tests, use of a multiple cylinder for fatigue tests and method of controlling the hydraulic drive’, for the main outcome of JRA1.3 (JRC Agreement: Co-Ownership Agreement between the European Union and Bosch Rexroth S.P.A: JRC Reference: JRC.BXL.CO.32692-2012)
- An EU patent application for the innovative test setup (TIM) and testing procedure designed at LNEC for the TA project "Masonry Enclosures", to allow in-plane and out-of-plane dynamic testing of masonry wall infill panels.
- A proposal to CEN to launch drafting of a European Standard for the qualification of research infrastructures in earthquake engineering, using as the basis the Common Protocol for the qualification of research infrastructures in earthquake engineering and its Technical Annexes (produced under Task NA2.4). The proposal is being formulated by SERIES beneficiary PeP and will be submitted to CEN by UNI (Italian Standardization Body), CEI (Italian Electro-technical Committee) and other national standardization organisations.